Cold Working of Brass

COLD WORKING OF BRASS

WITH SPECIAL REFERENCE TO CARTRIDGE (70-30) BRASS

by

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Chapter I—An Elementary Introduction

THE ALLOY OF 70% copper and 30% zinc, commonly known as cartridge brass or 70-30 brass, is a versatile member of the brass family. Perhaps the name is as descriptive as any brief one that could be devised to describe its properties — namely, a brass alloy of high strength and ductility, capable of deep drawing. This book will discuss some of the properties of the alloy and the means to control them. However, before proceeding, it might be well to review some of the basic facts concerning the brasses, as well as some of the terms and methods employed to measure their properties.

Ultimate Structure (*Atomic Arrangement*)

It should be understood ~~at the outset~~ that it is impossible to harden cartridge brass by quenching from a high temperature — an operation analogous to the quench-hardening of steel — or by quenching from a more moderate temperature and "aging" by holding for a considerable time at a slightly elevated temperature — the latter being an operation analogous to the age-hardening or so-called "precipitation hardening" of the strong aluminum alloys. Heat treatments coming under the classification of "annealing" — moderately slow heatings and coolings — are of great value in adjusting the physical properties of cartridge brasses at various stages of manufacture ~~as we shall~~ see

~~later on~~, but it is repeated that the alloy cannot be *hardened* by quenching or other heat treatment.

The reason for this is that cartridge brass is a single-phase alloy. Under the microscope the metallic grains, the crystals that make up the metal, are made up of a single constituent, known as "alpha solid solution" or "alpha brass". stet ~~These terms might also be explained with profit to the general reader.~~

• He would not be surprised, on looking through a microscope at a polished section of pure copper, ~~for example, to find that~~ the metal ~~was~~ all alike. ~~What he would see would~~ look like Fig. 1, on the ~~insert facing~~ page 10. It would have the clear red color of untarnished copper, and the various fine units of the microstructure would naturally be alike in their essential nature. It would not be surprising to find a considerable variation in *size* of these constituents, and even of their color tones, but since the metal is known to be pure copper, *all* of what he would see would be nothing but copper. The metallurgist would say that it has a "single phase" structure. ~~(For "phase" read "substance".)~~

The appearance of numerous straight lines on the polished surface would suggest that these grains have an orderly inner construction, even though their outer edges may have a meandering course. This is in fact true. By X-ray and other evidence it has been demonstrated that the copper atoms arrange themselves in these grains in a perfectly regular geometric way, building up in space a true crystalline structure. The finest "unit" of this structure known as the crystalline lattice is an imaginary cube, whose edge is 0.00000036 mm. long. An atom of copper occupies the corner of each such cube, and another is in the center of each cube's face. In scientific parlance we would say that the crystalline lattice of copper is "face-centered cubic" with lattice constant of 3.608 Angstrom units.

~~Now~~ what happens to this crystalline structure when the alloy is not pure copper, but is only 70 parts copper and 30 parts zinc (cartridge brass)? ~~In natural colors a polished~~ section of such an alloy would look like Fig. 2, also on the insert facing ~~page 10~~. This sample ~~has~~ been etched slightly with a reagent known to emphasize the contrasts in its structure. The numerous grains are more universally traversed by straight bands, impelling evidence of the geometric inner structure. There is so much contrast that one might be tempted to say there must be more than one material here, that this is no longer a single phase structure, but has two phases or three phases, or even more substances contained in it. As a matter of fact, the structure is still a single phase structure; these stripes are known to crystallographers as "twinning bands", and are etching effects rather than anything else. The crystalline lattice on one side of a twinning plane is merely a mirror-reflection ~~(left-handed replica, so to speak)~~ of the lattice on the other side.

~~Now,~~ how can copper and zinc alloy together in a single phase structure? It so happens that the zinc atoms bodily replace copper atoms here and there, at random, throughout the cubic lattice. This replacement process can continue until the alloy contains even more zinc than the 30% required to make cartridge brass; a new structure does not appear until more than about 37% zinc, by weight, is alloyed with the copper. The dimensions of copper's unit cell are enlarged a little as more and more zinc enters, but the structure is still face centered cubic. The replacement of the required number of copper atoms by zinc is done in a random manner, and is not confined to certain geometric positions, but the whole thing averages out. Metallurgists would say we have here a "solid solution" of zinc in copper — ~~really a happy term~~ — and this particular solid solution was long ago named "alpha brass".

Now since the zinc atoms are lost among the copper atoms, and the copper can absorb in this manner much or little zinc, alpha brass is truly a solid solution of the two metals. There is only one "phase". Fundamentally this is the reason why the alpha brasses (including cartridge brass) cannot be quench hardened; all alloys that may be hardened by heat treatment contain more than one phase, and the hardening phenomenon is associated with different solubilities of these phases or constituents, each in each, at various temperatures. Since cartridge brass does not quench-harden, it will be unnecessary to dwell on this particular hardening mechanism in two-phase alloys.

Hardening by Cold Work

~~Now,~~ since cartridge brass cannot be hardened and strengthened by quenching the only manner in which physical properties may be varied is by cold working or by annealing. By "cold" is meant the ordinary room temperatures encountered in fabricating brass, as contrasted to hot working which usually means, for copper-zinc alloys, working the metal when it is heated to some temperature between 1200 and 1600° F.

In the drawing or fabrication of a cartridge case, or any other similar article, the cold forming process increases the tensile strength and hardness but at the same time decreases its ductility and toughness — that is, its capacity for absorbing further cold work. This is an action typical of many metals. As in other materials, there is some point in the cold forming process at which ductility is no longer sufficient to allow further deformation. Hence, annealing or softening is required before further reduction can proceed. The extent to which the softening or annealing takes place is dependent upon the amount of previous cold deformation, and upon the annealing cycle — that is, the temperature to

which the metal is heated, and the time it is held at that temperature. Consequently, the cold working and annealing relationships go hand in hand and one cannot be changed indiscriminately without affecting the other.

It would doubtless be interesting here to stop long enough to give a simple, scientific explanation of why cold work has such an important effect on a single phase metal. Unfortunately it is impossible to do so because metallurgists and physicists are not yet able to explain to their own satisfaction why this is so. An undisputed fact is that cold work seems to fragment the crystals without actually causing them to fall apart. The size of the average grain is therefore reduced by cold work. Numerous theories have been advanced, as to why this should harden and strengthen the metal, but none fit all the experimental facts. Consequently we will confine the discussion to the latter, and will merely show the consequences of cold work without attempting to say *why* such actions ensue.

The effects of annealing are readily observed under the microscope, as far as changes in grain size are concerned. ~~While a fuller~~ account of the phenomenon ~~will be given~~ in ~~later pages~~, it may be said here that the ~~same~~ favorably situated grains start to grow at a certain temperature known as the "recrystallization temperature" — grow in the sense that atoms from surrounding grains attach themselves to the active one in such a manner as to extend its crystalline lattice in all directions. This growth continues as time and temperature permit. A number of laws have been discovered concerning this action; among them the principal ones are first, that the more heavily the brass is cold worked the lower will be its recrystallization temperature, and second, that as annealing temperatures are higher and higher, and annealing times longer and longer, the resulting average grain size is larger and larger.

It is important in setting up the cold working and annealing cycles that the proper relationship be established to meet the properties required, either in cartridge cases or other articles, because the physical properties of the cold worked material are different from those of the annealed brass. In order to maintain the fastest production rate and the highest quality, this ratio should be held within the necessary limits as specified or required for the intended use. Later discussion will describe briefly the limits indicative of those required. The operating limits must be established by experimenting with the actual equipment at hand; theoretical considerations can give only an idea as to how corrective measures can be applied.

Hardness Designations

It might be well also to review the methods used to describe cold working and annealing and their extent.

It is the custom to refer to cold rolled (reduced) metals by such terms as "quarter hard", "full hard", "spring hard". In Table I their meaning is shown in relation to the Brown & Sharpe gage system. This gage system, much used in all branches of the copper and brass industry, is

Table I — Classification of Cartridge Brass by Cold Work

Temper Designation	Nominal Reduction B & S Gage No.	Per Cent Reduction (Approx.)	
		Sheet & Strip	Rods, Round Shapes, Etc.
Quarter hard	1	10.9%	20.7%
Half hard	2	20.7	37.1
Three-quarter hard	3	29.4	50.0
Hard	4	37.1	60.5
Extra hard	6	50.0	75.0
Spring	8	60.5	84.4
Extra spring	10	68.7	90.2

Table II — Decimal Equivalents (Inches) for Various Gages

Gage	B & S or A.W.G.	B.W.G. or Stubs'	W & M	British Std.	London	U.S. Std.	Manufacturer's Std.
0000	0.4600	0.454	0.3938	0.400	0.454	0.406	
000	0.4096	0.425	0.3625	0.372	0.425	0.375	
00	0.3648	0.380	0.3310	0.348	0.380	0.344	
0	0.3249	0.340	0.3065	0.324	0.340	0.312	
1	0.2893	0.300	0.2830	0.300	0.300	0.281	
2	0.2576	0.284	0.2625	0.276	0.284	0.266	
3	0.2294	0.259	0.2437	0.252	0.259	0.250	0.2391
4	0.2043	0.238	0.2253	0.232	0.238	0.234	0.2242
5	0.1819	0.220	0.2070	0.212	0.220	0.219	0.2092
6	0.1620	0.203	0.1920	0.192	0.203	0.203	0.1943
7	0.1443	0.180	0.1770	0.176	0.180	0.188	0.1793
8	0.1285	0.165	0.1620	0.160	0.165	0.172	0.1644
9	0.1144	0.148	0.1483	0.144	0.148	0.156	0.1495
10	0.1019	0.134	0.1350	0.128	0.134	0.141	0.1345
11	0.0907	0.120	0.1205	0.116	0.120	0.125	0.1196
12	0.0808	0.109	0.1055	0.104	0.109	0.109	0.1046
13	0.0720	0.095	0.0915	0.092	0.095	0.0938	0.0897
14	0.0641	0.083	0.0800	0.080	0.083	0.0781	0.0747
15	0.0571	0.072	0.0720	0.072	0.072	0.0703	0.0673
16	0.0508	0.065	0.0625	0.064	0.065	0.0625	0.0598
17	0.0453	0.058	0.0540	0.056	0.058	0.0562	0.0538
18	0.0403	0.049	0.0475	0.048	0.049	0.0500	0.0478
19	0.0359	0.042	0.0410	0.040	0.042	0.0438	0.0418
20	0.0320	0.035	0.0348	0.036	0.035	0.0375	0.0359
21	0.0285	0.032	0.0317	0.032	0.0315	0.0344	0.0329
22	0.0253	0.028	0.0286	0.028	0.0295	0.0312	0.0299
23	0.0226	0.025	0.0258	0.024	0.0270	0.0281	0.0269
24	0.0201	0.022	0.0230	0.022	0.0250	0.0250	0.0239
25	0.0179	0.020	0.0204	0.020	0.0230	0.0219	0.0209
26	0.0159	0.018	0.0181	0.018	0.0205	0.0188	0.0179
27	0.0142	0.016	0.0173	0.0164	0.0188	0.0172	0.0164
28	0.0126	0.014	0.0162	0.0148	0.0165	0.0156	0.0149
29	0.0113	0.013	0.0150	0.0136	0.0155	0.0141	0.0135
30	0.0100	0.012	0.0140	0.0124	0.0138	0.0125	0.0120
31	0.0089	0.010	0.0132	0.0116	0.0123	0.0109	0.0105
32	0.0080	0.009	0.0128	0.0108	0.0113	0.0102	0.0097
33	0.0071	0.008	0.0118	0.0100	0.0103	0.00938	0.0090
34	0.0063	0.007	0.0104	0.0092	0.0095	0.00859	0.0082
35	0.0056	0.005	0.0095	0.0084	0.0090	0.00781	0.0075

B & S (Brown & Sharpe's) or A.W.G. (American Wire Gage) commonly used for copper alloys. B.W.G. (Birmingham Wire Gage) or Stubs' Gage is used for copper and brass tubes. W & M (Washburn & Moen) is sometimes called U. S. Steel Wire Gage, Roebling, and American Steel & Wire Co.'s Gage, commonly used for steel wire. The British Standard Gage is also known as New British Standard, English Legal Standard, or Imperial Wire Gage. London is also known as Old English Gage for wire. The U. S. Standard Gage has been legalized for customs house use. The Manufacturers' Standard Gage has been adopted by The American Iron & Steel Institute for sheet steel.

based upon a constant percentage-difference between gage numbers, and it consequently follows that there is also a constant difference between any two given gage numbers the same number of digits apart. That is to say, the per cent difference between 10 and 14 B&S gage numbers is the same as between 22 and 26 B&S gage numbers. stop This statement can be checked by a little arithmetic applied to Table II of decimal equivalents.

Practically speaking, this difference in gage numbers also represents an amount of cold reduction — for strip a reduction in thickness, and for rounds a decrease in area. Consequently, the term "quarter hard", as an example, means a cold reduction, from an annealed state, of 1 B&S number to final thickness. ~~It will be~~ seen later that, for a given alloy, it also corresponds to definite physical properties (within commercial limits) of the metal after that amount of cold reduction has been performed. Hence, the terms in column one of Table I are definite descriptions of physical properties of 70-30 brass and are so used in this ~~article~~ as well as by the trade.

Thick plates and similar heavy gage metal are not within this category, since mill equipment is not capable of the cold reductions required.

It will be noted that the last column is headed "Rods, Round Shapes, Etc." These figures for approximate reduction (per cent) are based on *area* difference before and after cold working, and are used, as the title denotes, for round shapes particularly; it is important to note that the amount of reduction for four B&S numbers is not the same for a round section as it would be for strip. It is preferred practice in the plants of Revere Copper & Brass, Inc., to use the *percentage* reduction of cold working when speaking of rounds, rather than a number, because of its greater accuracy and freedom from ambiguity.

In summation, the larger the cold reduction, or greater the "numbers hard", the greater is the tensile strength, hardness and, at the same time, the lower the elongation and reduction in area (the extent of change depending upon the alloy). These points will be demonstrated quantitatively for cartridge brass in a later chapter.

Use of Grain Size Measurements

The measurement of the effects of annealing uses a system which specifies the average diameter of the crystals in millimeters after heat treatment. This figure is commonly known in the trade as "grain size". The best descrip-

Table III — Classification of Grain Sizes

Nominal Grain Size	Typical Use
0.015 mm.	Slight forming operations.
0.025	Shallow drawing (automobile hub caps).
0.035	Best average surface after cold working (automobile head lamp reflectors).
0.050	Average drawing operations.
0.100 and greater	Heavy draws — thick gages.

tion of the value and the actual sizes may be seen in the standards of the American Society for Testing Materials. The chart furnished in these standards is reproduced as Fig. 3, and shows the actual size of the crystals at the usual magnification of 75 diameters.

Table III tabulates commercial grain size ranges, and types of familiar operations in these various classifications which would be applicable to 70-30 brass — or to a similar alloy known as deep drawing brass (67% copper, 33% zinc, nominal analysis).

Figures will be presented in a later chapter to make it obvious that the larger the grain size the softer the metal,

which is shown by lower tensile strength and increasing elongation and reduction of area. Within commercial limits of furnaces and annealing equipment, there are definite minimums and maximums which can be obtained. These also will be discussed later.

General Properties of 70-30 Brass

In reference to cartridge brass and its particular metallurgical properties, increasing the zinc content of a red brass★ will increase the strength and also increase the elongation and reduction of area in the tensile test piece up to the approximate composition of cartridge brass (30% zinc); above this point the elongation (and reduction of area) starts to decrease but tensile strength continues to increase. In effect, this means that the ratio between the elongation and tensile strength is at its highest, which is quite important in the fabrication of cartridge cases or other difficult deep drawing articles. Modern cartridge cases, especially some developed in the course of World War II, represent extremes of difficulty which are met but rarely in ordinary peacetime production. It is in the production of some of these cases that the properties of tensile strength and its plasticity in cold working are most important.

To over-simplify the problem, in the course of drawing with a die and a mandrel there are forces which are exerted to distort the metal into a new shape and, at the same time, stress the metal very considerably. Hence, an alloy which will successfully cold deform must be strong enough to resist the tensile or other stresses tending to fracture, as well as be ductile (plastic) enough to conform to the new shape being produced. The first operation of forming a cup from a disk, as shown in Fig. 4, is especially severe.

★A "red brass" is a copper-zinc alloy with 15% zinc.

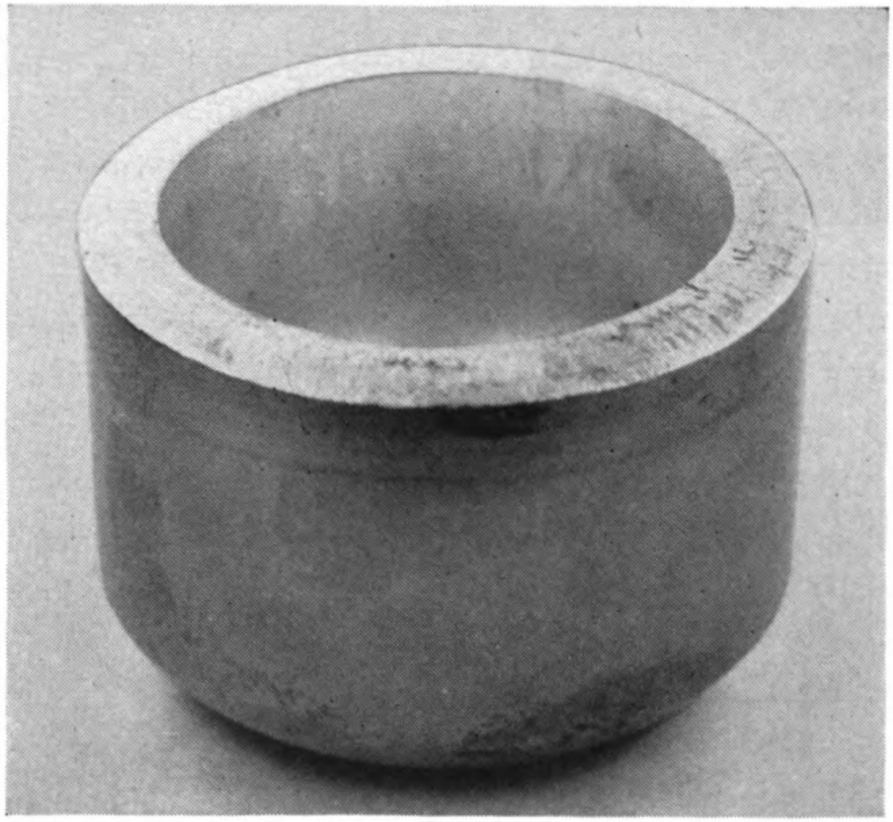

Fig. 4 — A Cup Formed From a Flat Sheet or Strip Is a Searching Test of Metal's Quality

Among all of the brasses, 70-30 has this combination of working properties to the greatest degree for cupping and deep drawing, which explains why it is specified particularly for cartridge cases (copper content 68.5 to 71.5% in most Government specifications). This alloy can be worked in a minimum number of operations to produce deep drawn parts, thus requiring the fewest pieces of mechanical equipment and in-between anneals. These properties also are important in the actual use of the case itself, as those familiar with the problem well know.

Influence of Copper Content

The increase in strength with increasing copper content is shown in Fig. 5, which is self-explanatory. The figures shown are only approximate; they are for annealed

material and intended as a guide rather than for absolute values.

As long as this chapter is headed "An Elementary Introduction" it may be read by some who are not familiar with the standardized methods of making tension tests. For their edification, and to avoid turning to the last chapter for a fuller explanation, it might be said that a strip or round specimen is machined from a representative sample of the metal under study, the form and dimensions of the specimen being standardized and shaped so its ends — usually enlarged — may be gripped securely in the testing machine and so the load to be imposed along the mid-length of the specimen will be distributed as uniformly as possible in all of this portion. The cross sectional area of this middle portion of the test piece is carefully measured. A small device for measuring accurately the extension under load is also attached to the test piece before it is strained; this is called an "extensometer". The results are usually figured on the basis of "per cent elongation in a 2 in. gage length".

The tensile testing machine is merely an accurate device for imposing a measured pull exactly along the axis of such a test piece. By means of appropriate dials, the imposed load can be measured at any time. Simultaneously the extensometer tells the observer how much the test piece has stretched under this load. Loads are usually increased at a slow and standardized rate (noting elongations at frequent intervals) until the piece breaks. Knowing the load at fracture and the original cross sectional area, the ultimate tensile strength can then be computed; the permanent elongation by plastic flow during the later stages of the test is also easily read by extensometer, or by reassembling the broken specimen and measuring the length between gage marks, originally placed exactly 2 in. apart. These two values are the ones plotted in Fig. 5.

It should also be noted in Fig. 5 that as the copper content changes, the effect of temperature after cold working also changes. That is to say, for a given annealing temperature an increase in content of copper means that a larger grain size will be obtained. However this remark applies to the alpha brasses as an entire family — chemical specifications for a particular member of the family, such as cartridge brass, are written so that the grain refinement and growth under a given set of physical conditions will be reproducible. Variations in cold working and annealing

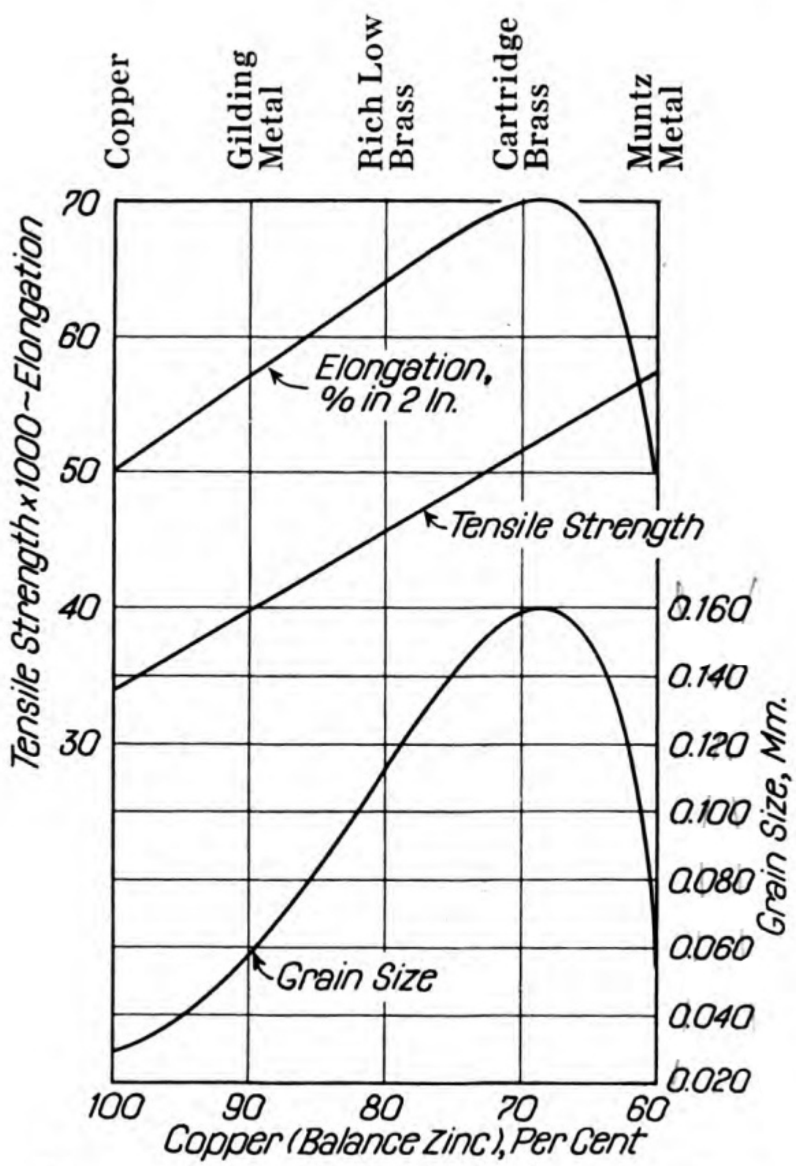

Fig. 5 — General Influence of Copper Content on Properties of Annealed Brass

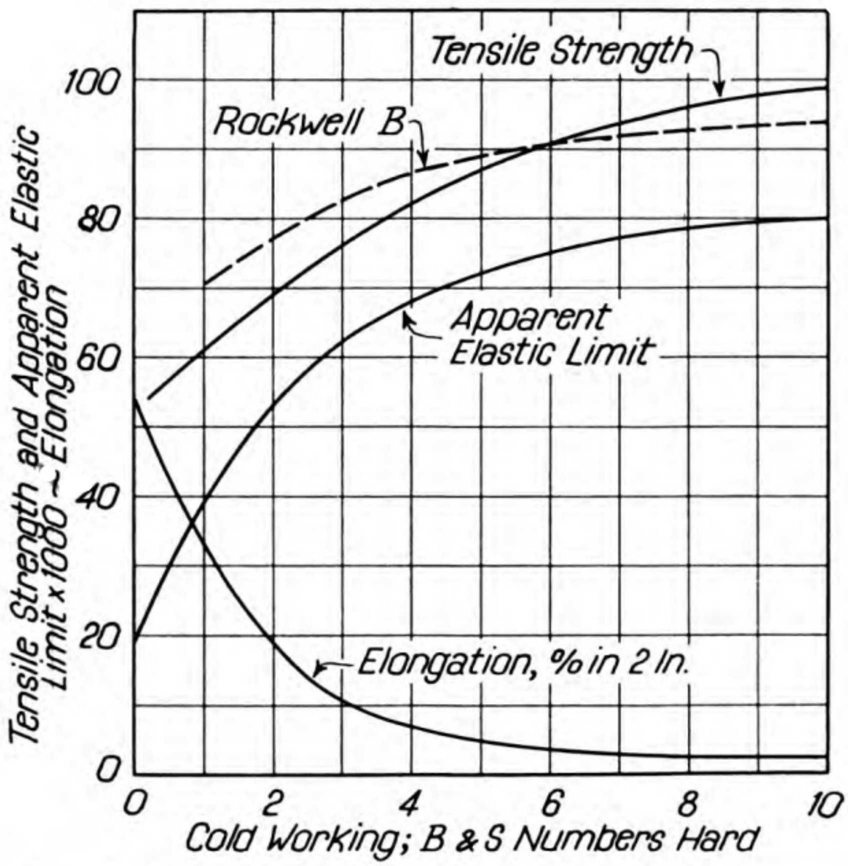

Fig. 6 — Influence of Cold Rolling on Cartridge Brass Strip

cycles will cause a far greater difference in grain size than fluctuations in copper content, within the specified limits. (Since a new and second constituent known as beta brass appears within the range of copper content of 58 to 63, approximately, crystals of beta tend to obscure the actual grain size and be responsible, in part, for the downward trend of the lower curve in Fig. 5, as it refers to the higher zinc alloys.)

Effects of Cold Work

The specific properties of 70-30 brass are shown in Fig. 6 and 7, representing the effects of cold working and annealing, respectively.

Figure 6 notes the increase in tensile strength, "appar-

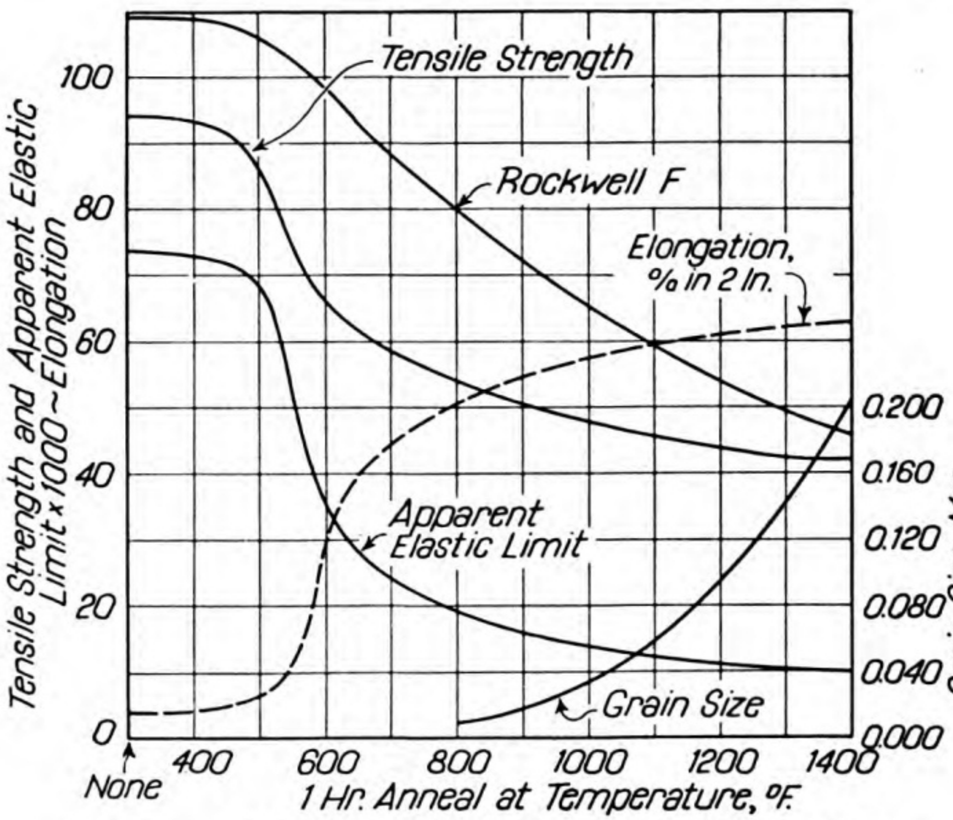

Fig. 7 — Physical Properties of 70-30 Cartridge Brass, Cold Rolled 6 B&S Numbers Hard, Then Annealed 1 Hr. at Various Temperatures

ent elastic limit"*, and Rockwell hardness as cold working (in terms of B&S numbers) increases.

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*The "apparent elastic limit" is a point above which increase in strain or elongation is no longer at the same rate as increase in stress or load. This value is generally a conservative figure for designers to use, and for many copper alloys and conditions is lower than the "0.5% yield point" which is the stress per square inch required to strain or stretch the test piece 0.5% of its gage length. This detail of testing technique is discussed at length in the last chapter. This effect is typical for copper-zinc alloys of the alpha type except that those with lower copper content tend to "level off" as the cold working reaches the range of 8 and 10 numbers hard, and a very definite maximum (considering commercial equipment) tends to be reached. The *absolute* maximum depends on the shape of the article being cold worked, which commercially is usually reached in the form of wire.

Effects of Annealing Temperature

Figure 7, indicating the change in properties due to the application of heat, is predicated upon a given amount of cold working prior to the application of heat. This relationship will be discussed in a later chapter.

Commercial practice on cold rolled (cold worked) material will range from extremely slight amounts of cold work for very special uses up to and including the tempers between 8 and 10 numbers hard in strip form. In rod and tubular form these heavy reductions cannot be achieved, as a rule.

Grain sizes in annealed metal, as shown in Fig. 7, vary somewhat according to gage and, as Table III on page 9 notes, most light gage metal is furnished with grain sizes varying between 0.010 mm. and 0.050 mm. As the gage increases and the severity of the operation increases, the grain sizes are considerably larger. The material going into cartridge cases will be in excess of 0.055 mm. — a grain size seldom used in peacetimes.

It is difficult to define, exactly, "light" gages and "heavy" gages, but light gages, commercially, will mean somewhat less than 0.075 in. (say 13 g., B&S, and thinner) and heavy gages over 0.075 in. (say 12 g., B&S, and thicker). It should be noted that the relatively heavy material — over ¼ in. — being used for certain types of cartridge cases represents wartime practice and does not constitute the largest peacetime uses. The lighter gages with resulting smaller grain sizes are in more general use, largely because of surface effects to be discussed later.

Footnote on Rockwell B and F

It will be noted that Fig. 6 has a line marked "Rockwell B" and Fig. 7 has one marked "Rockwell F". As is perhaps

superfluous to say, these are hardness numbers. Their correlation, together with other hardness scales, are shown in the large diagram, Fig. 51, inserted into the text of the last chapter, facing page 98.

Hardness of metals is measured by pressing a small hardened sphere or pointed indenter into a smoothed surface, using a standardized load. The softer the material the larger (or deeper) the indentation; the harder the material the smaller (or shallower) the indentation. Hardness numbers are derived from the dimensions of this indentation so that low numbers represent softer metal than the higher numbers.

Various scales have been used on various metals; certain commercial hardness testers use pointed diamonds, others use hard steel balls. Size of indenters and indenting loads are also selected appropriate to the metal under test, or the ideas of the manufacturers. Some equipment is all but automatic, the hardness of the metal under test being read from an indicating dial.

Chapter II—Cold Working and Annealing

IN the previous chapter it was briefly pointed out that:

1. Brasses are not susceptible to heat treatment for hardening, but that cold working is the only means of increasing strength and hardness.

2. Annealing following cold working restores ductility or workability, the extent of the annealing in time and temperature controlling the degree of ductility (grain size being the preferred means of measurement).

3. Cold working and annealing go hand in hand and one cannot be changed indiscriminately without affecting the other.

"Break-Down", "Run-Down" and "Finishing" Operations

In a brass mill, cold working and annealing relationships are established through long practice for the various products (sheet, strip, rods, tubes and shapes) and thus the properties are controlled in the "break-down" and "run-down" stages, as well as in the finishing operations — "break-down" and "run-down" being the primary and intermediate steps required to reduce a raw cake into sheet and strip, or a billet into rods, tubes or shapes, nearly to the physical dimensions desired by a customer. For sheet and strip these operations consist of either hot rolling or cold rolling for breaking down, depending upon mill equipment;

for other forms, break-down and run-down consist of hot rolling or hot extrusion operations. Running down is usually a cold working operation for all forms of brass.

For the cold working operations, the three basic principles stated above are applied; that is, cold reductions as well as annealings in intermediate steps are standardized, a rough rule for sheet and strip being 50% reduction, fol-

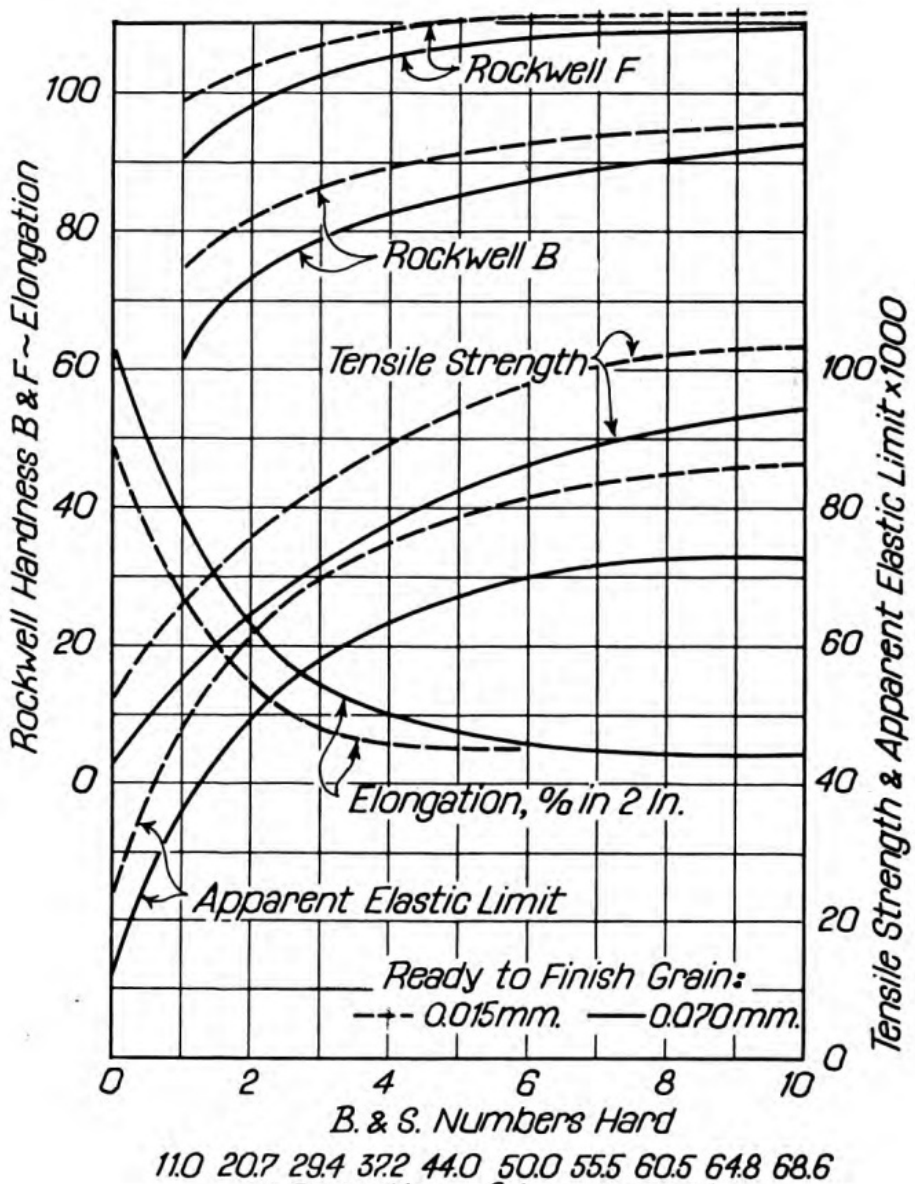

Fig. 8 — Cold Worked Sheet and Strip: Effect of Ready-to-Finish Grain Size (0.015 and 0.070 Mm.) on the Tensile Properties and Hardness of Cartridge Brass Strip After Definite Reductions by Cold Rolling

lowed by an anneal for an approximate .050-mm. grain size minimum. Actual reductions on rod, tubes and shapes are not so simply arranged, because mill equipment for the most economical production sequences may not be available, and because of limitations on size and shape. Obviously, it is well to avoid cold working the alloy near its limit (the maximum possible before ductility becomes so low that fracture occurs). Subsequent annealing is primarily designed for economical time and temperature cycles. Desirable grain size averages 0.035 to 0.050 mm. for 70-30 brass; higher copper alloys will anneal smaller in grain size, as shown by the lower curve in Fig. 5, page 13.

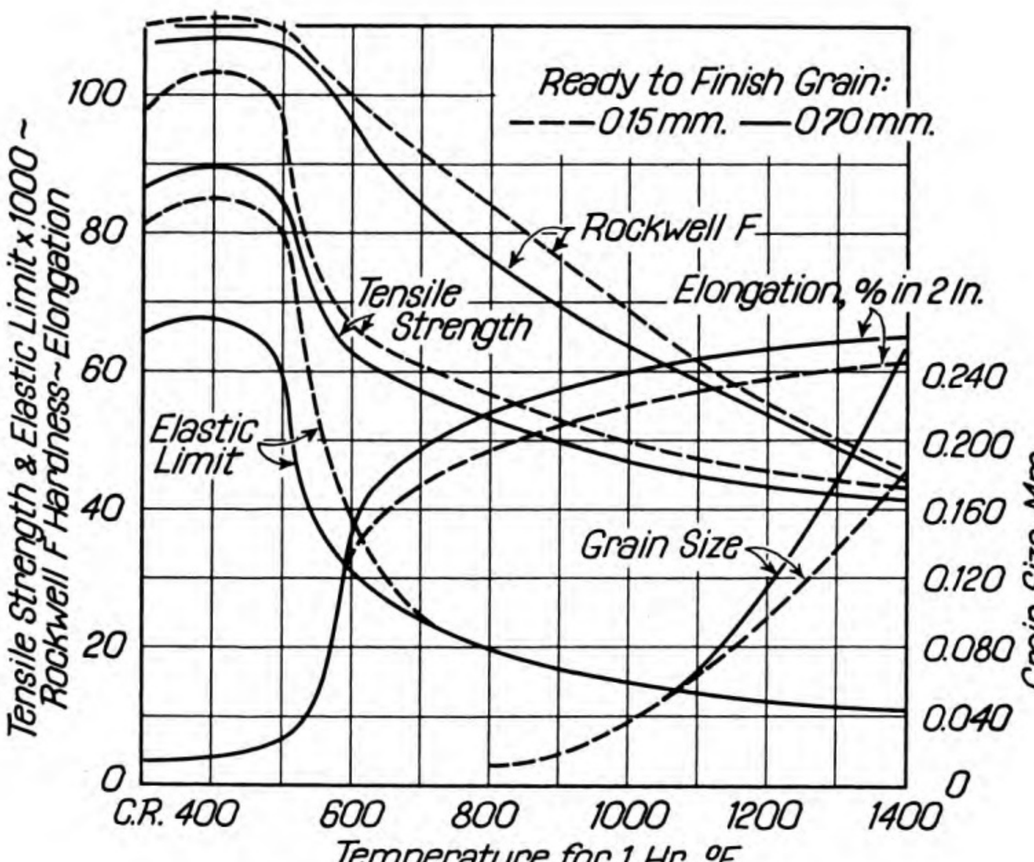

Fig. 9 — Annealed Strip After Cold Working: Effect of Ready-to-Finish Grain Size (0.015 and 0.070 Mm.) on the Tensile Properties and Hardness, as Well as the Final Grain Size, of Cartridge Brass Strip Cold Rolled 6 B&S Numbers Hard and Then Annealed 1 Hr. at Temperatures Indicated

The finishing operations not only must produce dimensions and accurate shapes ordered by customers within the required tolerances, but also the physical properties best fitting the application to which metal is being applied. This may be determined by specifications of government agencies, national societies, the customer, by experience of the mill with the customer's requirements, or on recommendation according to operations or application by a technical advisor (or similar engineering sales organization). In any event, mill operations must be arranged to end up with the properties to do the job at hand in the purchaser's plant. Considering some of the variables involved, this is not always as simple as it sounds.

Specific Effects of Cold Work in Finishing Operation

Cold working increases tensile strength,* apparent elastic limit and hardness, and decreases elongation and reduction of area — no matter if this cold working is by reduction through rolls for sheet or strip; through a round die for wire; through a die or rolls for rods, bars and shapes; or a die with inside mandrel or "plug" for tubes; or in subsequent fabrication in stamping and drawing, using dies and mandrels (punches). In all these operations the principle is the same: Cold working reduces the metal's capacity to absorb more cold work, and leaves its impress on the tensile properties reported by the testing engineer.

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*It is assumed in this and following chapters that the reader is fairly familiar with the technique of physical testing. Some of its phases which require special consideration in the acceptance testing of cartridge brass (and copper alloys generally) are discussed in Chapter VI. For a general treatment one may consult "The Testing and Inspection of Engineering Materials" by Davis, Troxell and Wiskocil, and "Materials Testing" by Gilkey, Murphy and Bergman, both published by McGraw-Hill Book Co.

Importance of Grain Size Control

The following discussion is intended to show the importance of these principles and how they may be applied. To aid us we will consider several charts of physical properties. Figure 8 applies to cold worked sheet and strip in relation to "ready-to-finish" grain size. Figure 9 applies to annealed sheet and strip after cold working. Figures 10 and 11 are for rod. Discussion of Fig. 10 and 11

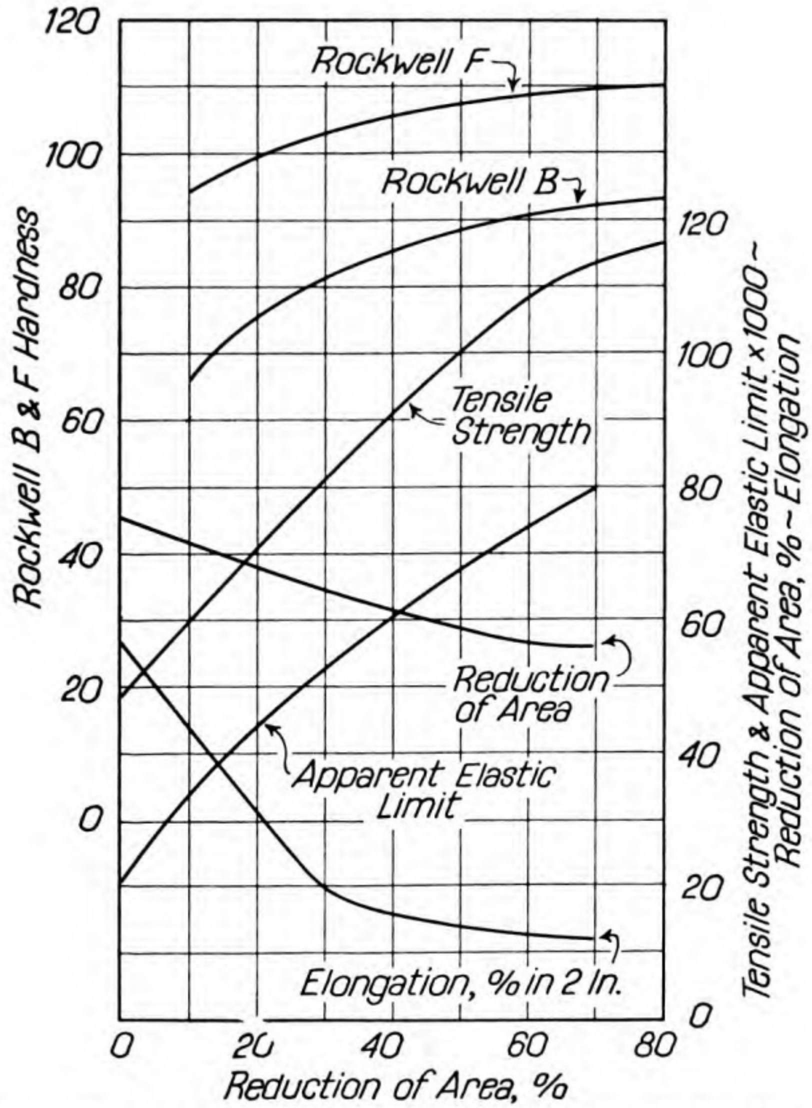

Fig. 10 — Cartridge Brass Rods (Nominally 70% Copper, 30% Zinc), in Diameters up to 1 In. and Ready-to-Finish Grain Size 0.045-Mm., Were Cold Drawn Various Amounts and Then Tested for Tensile Properties and Hardness

applies to the ready-to-finish grain size of 0.045 mm., indicating average conditions. The elongation in 2 in., determined in the tensile test on rod, is more indicative of the actual elongation of 70-30 brass than elongation values for strip of approximately the same past history of cold reduction and annealings.

The physical properties of a finished part or form made of brass depend on the last operation. The amount of cold

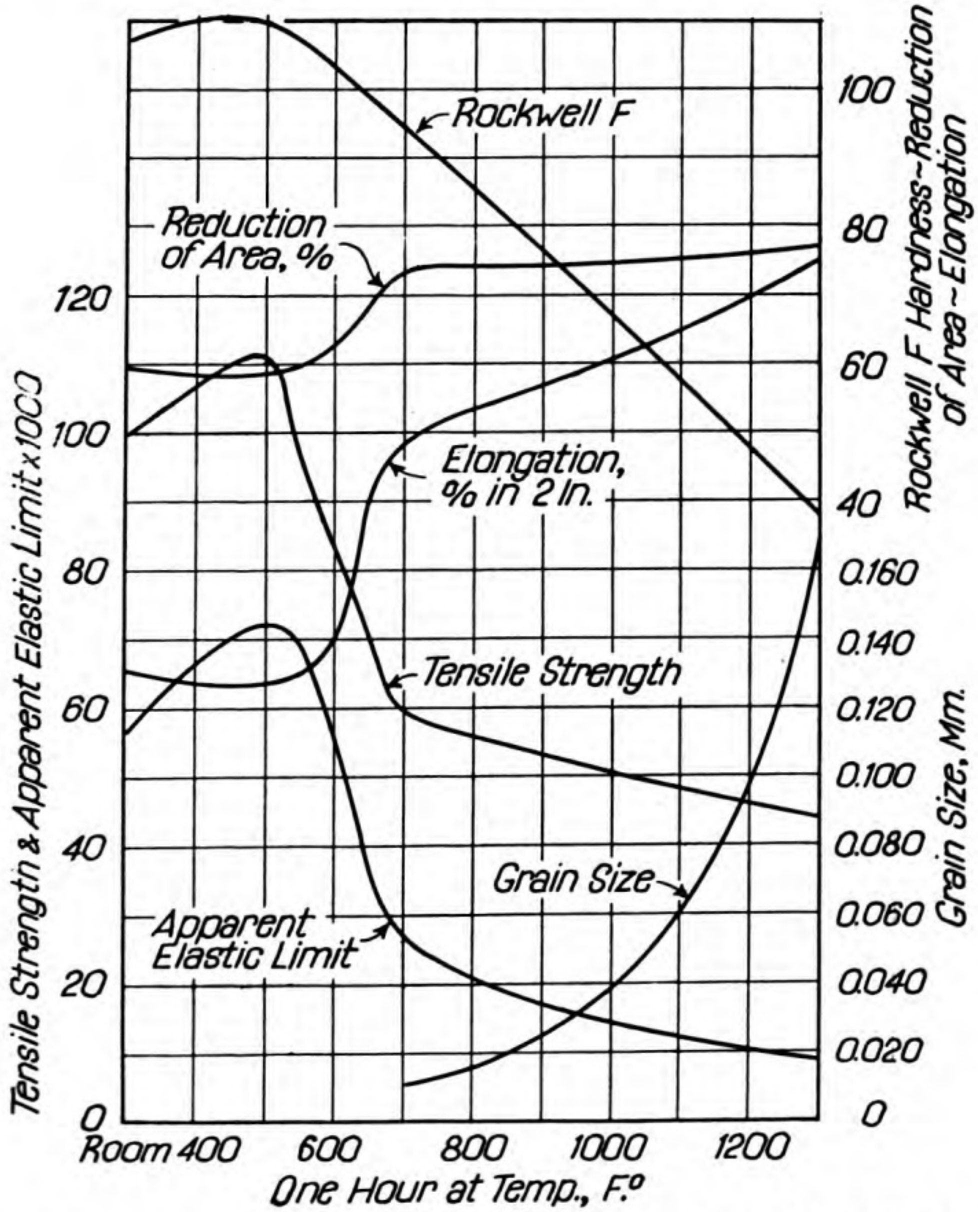

Fig. 11 — Cartridge Brass Rod of Fig. 10, Cold Reduced 50%, Was Annealed 1 Hr. at Various Temperatures. Curves show resulting tensile properties, hardness, and grain size

working in that operation necessarily must be enough to meet the specification. Figures 8 and 9 indicate how much this reduction needs to be. If a tubular shape is involved, the cold working must be applied to the inside as well as the outside, in the majority of operations, because of surface, dimension and tolerance; "reduction" is therefore based on area as well as wall thickness. Simultaneously, the anneal prior to this final operation has an effect, as Fig. 8 indicates. Characteristically, a large ready-to-finish grain size lowers strength, as compared to a small ready-to-finish grain size.

Differences exist also for hardness and elongation, but lack of sensitivity of test methods tends to obscure these differences. In this connection the Rockwell F scale for hardnesses reading over 100 is not reliable. Furthermore, Rockwell B hardness scale should not be used when greatest accuracy is required on brasses over six numbers hard, because differences between small amounts of cold working are not easily detected by hardness tests; tensile strength is a better criterion. Approximate relations between tensile strength and elongation in 2 in. are shown in Fig. 12, and four commonly-used Rockwell hardness scales are marked on the horizontal coordinates. A conversion chart for hardness scales is shown on the insert facing page 98.

The variations in cold worked properties shown in Fig. 8 and 10 are important when, as an example, a specification requires a range, maximum to minimum tensile strength, of 10,000 psi. Brass mills, on a fairly wide range of products, consistently work to such a tolerance. Any parts maker, working similarly, will necessarily be required to control ready-to-finish grain size; whether it should be large or small depends on the results needed and the operations being performed, as will be brought out in a later discussion. The important thing for the present is this rule:

Once ready-to-finish grain size is established, hold it from lot to lot.

Otherwise, results will vary — as Fig. 8 shows. How closely grain size must be held will depend upon individual needs; Fig. 8 again is illustrative.

For typical physical properties for various cold rolled tempers, the range between 0.015 and 0.070 mm. ready-to-finish grain size for a given temper would provide a reasonable guide.

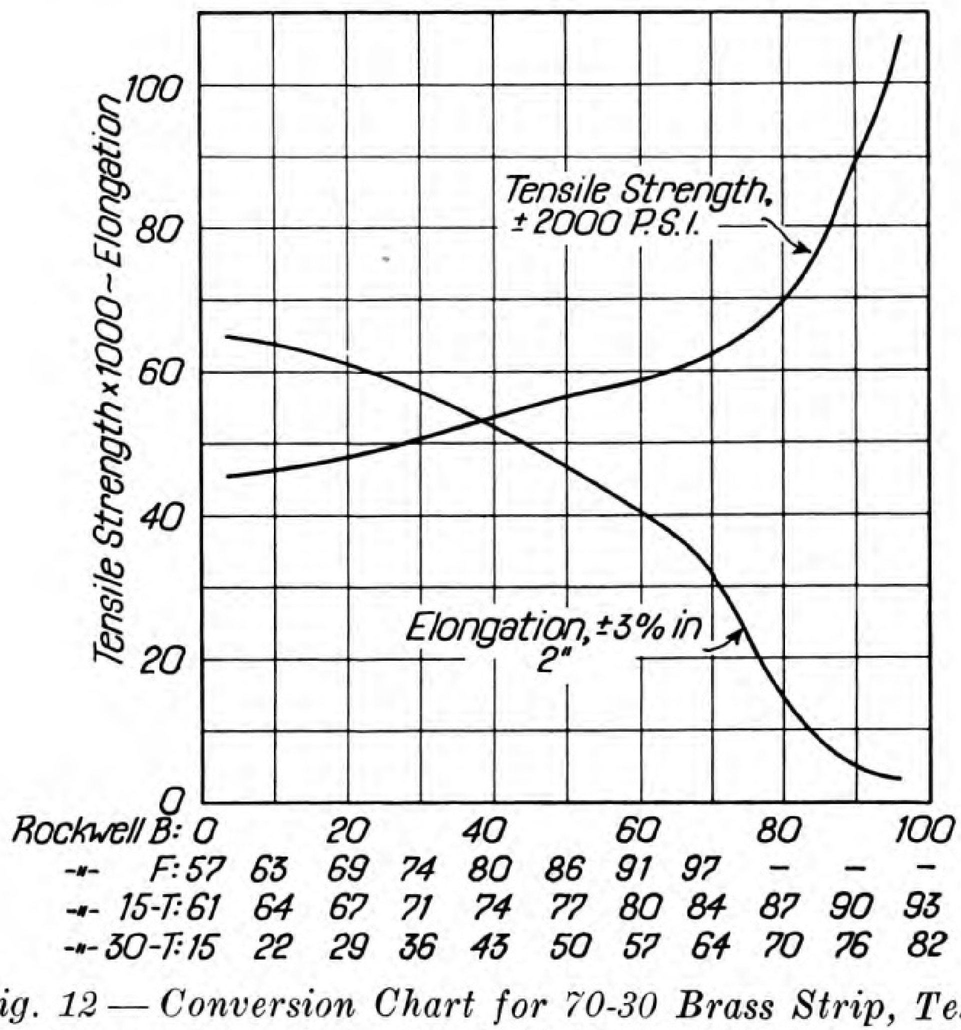

Fig. 12 — Conversion Chart for 70-30 Brass Strip, Tested for Hardness by Four Rockwell Scales Using $\frac{1}{16}$ In. Ball. Scale B imposes a 100-kg. load, F a 60-kg. load, 15-T a 15-kg. load, and 30-T a 30-kg. load. See also Fig. 51, facing page 98

Directional Properties

Usually, operations prior to ready-to-finish do not affect the final one (see Fig. 9) since the effects tend to "wash out" if the annealing after "run-down" is properly done. An exception is most commonly found in the rolling of copper or brass strip in which "directional properties" are produced and retained in spite of annealing. (By directional properties is meant the fact that the elongation of test pieces

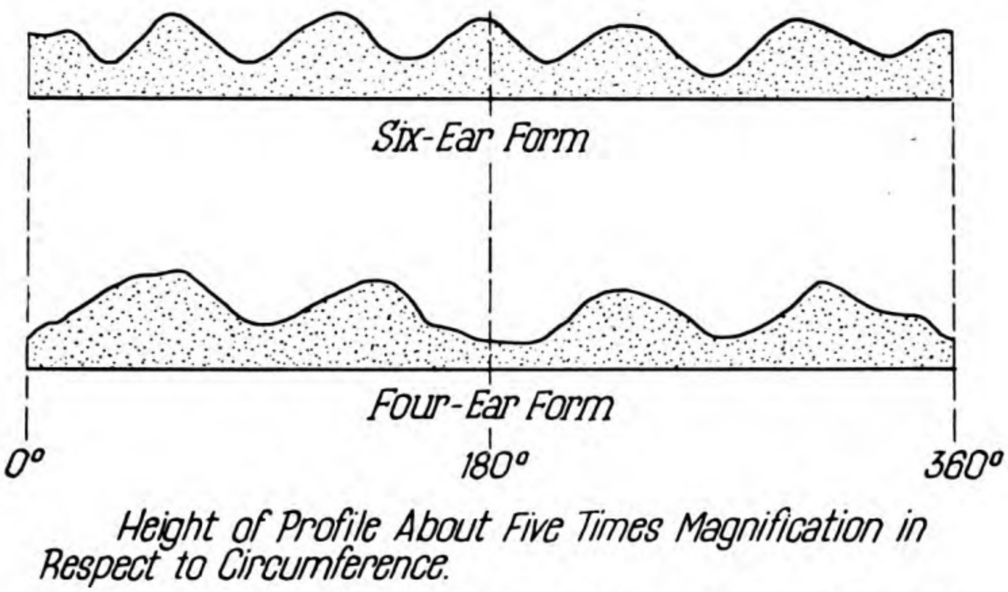

Fig. 13 — "Ears" Around Top Edge of Deep Cap Are Due to Tendency of Micro-Crystals to Assume Preferred Orientations After Heavy Cold Work and Rather Low Anneals (From "Effect of Some Mill Variables on the Earing of Brass in Deep Drawing" by E. W. Palmer and C. S. Smith, Transactions *A.I.M.E., 1942)*

cut from sheet at various angles to the direction of rolling is not uniform.) Evidence of this is found in the customer's plant during subsequent cupping operations, by the presence of "ears" about the periphery.★ Height of these ears or

★Ears due to preferred orientation should not be confused with one or two high spots found on the rim of a cup. This latter appearance is caused by gage variation in the strip.

high spots on the upstanding edges varies with the degree of directional properties, the magnitude of change of elongation, for example, with direction. Their location is in metal that originally was parallel to the rolling direction, and in metal that was originally 90° to that direction. This applies to copper, which has four ears, characteristically. In brass the four ears are usually located parallel to and 45° to the rolling direction, although six will appear when the zinc range enters that of drawing brass (34% Zn). The causes of earing vary, but most severe earing can result from a series of low temperature anneals, producing small grain size, followed by cold working of 4 to 6 B&S numbers.★

Microscopic Appearance of Cold Worked Brass

Cold work leaves its impress on the appearance of a microsection, best shown by fairly light work on coarse grain sizes (Fig. 14, page 28). Original grains are almost indistinguishable if ready-to-finish grain size is small, and final working is severe. In an article like a cartridge case head (Fig. 17, page 33) many degrees of cold work occur in a relatively short distance, and if such a piece is annealed, a wide variety of grain sizes would result.

Annealing, as is shown in Fig. 9 and 11, decreases tensile strength, apparent elastic limit, hardness, and increases

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Gage being thicker at one place than another results in more pressure between punch and die. Consequently metal flows more and the high spot results.

★For excellent detailed data on this subject refer to "Directional Properties of 68-32 Brass Strip" by H. L. Burghoff and E. C. Bohlen, as well as "Effect of Some Mill Variables on the Earing of Brass in Deep Drawing" by Earl W. Palmer and Cyril Stanley Smith. Both appear in the *Transactions* of the Institute of Metals Division of the American Institute of Mining and Metallurgical Engineers, Vol. 147, 1942.

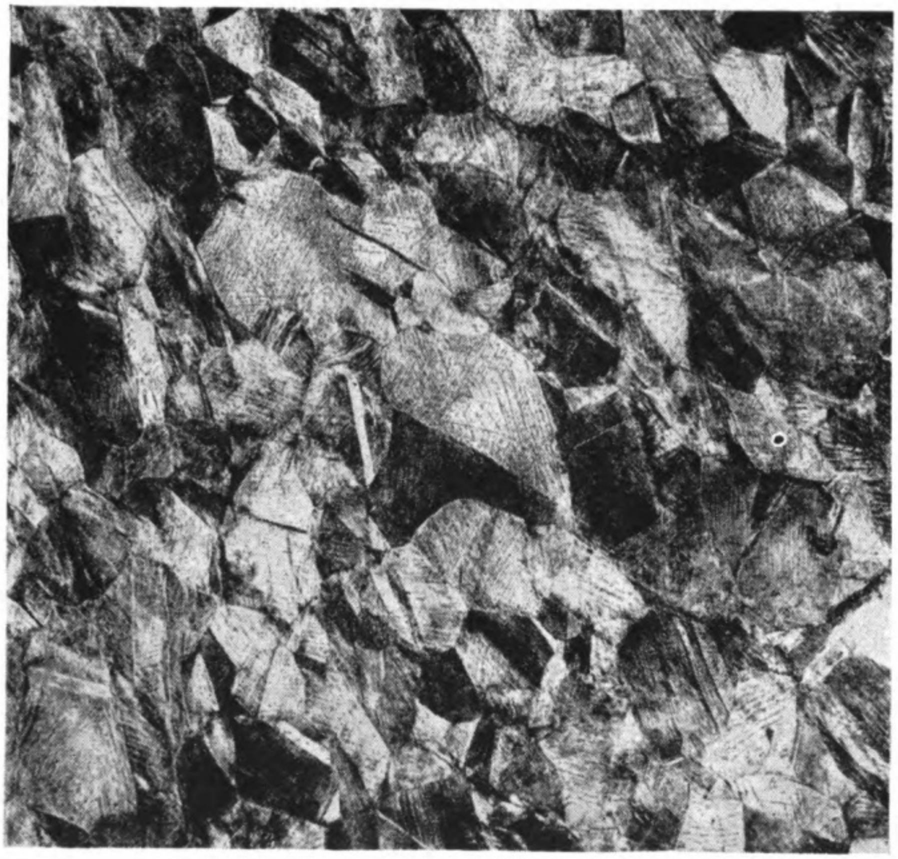

Fig. 14 — Coarse Grained Cartridge Brass After Relatively Slight Cold Working. Original grains are clearly distinguished, although numerous strain lines appear in all of them

elongation and reduction of area. At the same time, the distorted, stressed crystals typical of cold worked metal are replaced by characteristic equi-axed crystals shown in various grain sizes in Fig. 3, the grain size chart, facing page 11. As Table III in Chapter I denotes, varying uses determine the optimum grain size.

Annealing After Cold Work

The slight increase in strength and hardness after annealing at 400° F., as shown in Fig. 9 and 11, is typical of low temperature annealing. Annealing may be used to restore ductility for further cold working, or to remove

internal stresses due to cold working (when it is known as "relief annealing"), or to impart a specific physical property required by a particular use. The extent of the anneal in temperature and time is most dependent on the severity of the cold working which is to follow. (Relief annealing in

Fig. 15 — Same Brass as Fig. 14 After Much More Severe Cold Work. Crystals have become elongated and boundaries are impossible to distinguish. Structure might be called "fibrous"

the true sense does not soften or recrystallize the metal, and will be discussed as a separate subject.)

Results obtained by annealing depend upon several factors, which will now be enumerated and discussed. These principles are applicable to copper and all non-age-hardening copper base alloys, the degree and absolute values of properties varying with the alloy.

1. As prior cold working increases in severity, the lower is the softening and recrystallization temperature. The speed of grain growth and recrystallization also tends to increase.

It is preferred to define "recrystallization temperature" as that temperature that produces a grain size of 0.010 mm. or less (Fig. 16). There are other definitions of more exactness, but the one given is practical enough for our use.★

In Fig. 9 and 11 it should be noted that the prior cold reduction is stated as 6 B&S numbers and 50% respectively. Consequently, these or other similar annealing curves show only those conditions of softening and grain growth which follows a given amount of cold work. If prior cold work is less, the curves tend to shift to the right; when there is very little, such as less than 10% cold reduction, they tend to become much flatter, and the characteristic sharp drop in tensile strength, for example, almost disappears, since the tensile strength before annealing is nearly the same as afterwards.

At the same time, with the *lesser* amounts of cold working other effects are noticed:

★For example, in Jeffries & Archer's classic "The Science of Metals", page 86 states that recrystallization is the change where the distorted grain structure due to cold work are replaced by new grains, whose diameter is approximately the same in all directions; and "the lowest temperature at which new grains visible under the microscope appear may be called the *recrystallization temperature*". Sachs & Van Horn's "Practical Metallurgy" also states (page 123) "The term *recrystallization limit* refers to the lowest temperature which produces complete recrystallization for a specific metal and [cold worked] condition". Obviously the determination of either value would depend so much on microscopic technique and instruments that large differences might be expected from different laboratories and observers. Consequently the proposal of a definite grain size, as in the text, will lead to precision and avoid misunderstandings.

(a) Upon annealing, the ready-to-finish grain size tends to be obtained. For example, if 0.035-mm. grain size metal is worked 5%, a grain size *less* than 0.035 mm. will not result from ordinary annealing, but rather, 0.035 mm. or larger, depending upon time and temperature. (It might be mentioned appropriately here that re-annealing of annealed metal is an uncertain process. The original speed of recrys-

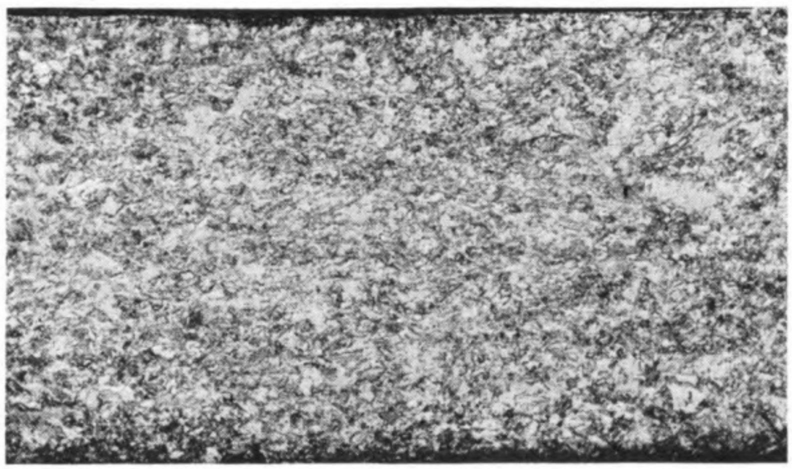

Fig. 16 — Recrystallized Brass (Fine Grained, Less Than 0.010 Mm.). Illustration is from the heavily-worked wall of a small-caliber cartridge

tallization and grain growth is lost and tends to be quite sluggish. In brass mill practice, therefore, if grain size were too small on the regular anneal and re-annealing was necessary to increase it to some required value, more frequently than not it would be necessary to try several times. Especially would this be true if an increase of 0.010 from, let us say, 0.030 to 0.040 mm. average is wanted. Obviously, if the grain size were too high, re-annealing would not reduce it, and unless further cold working could be applied, the metal would have to be used elsewhere or scrapped.)

(b) Light cold working may increase hardness (particularly since the determination of hardness of thin sections is largely a surface test), yet metallographic examination

may show slight evidence of cold work or no such evidence at all, either by strain lines or by deformation. This is typical of several mill operations, such as light passes on strip for stiffening the piece to give it better blanking properties, or "sinking" in tube making, which is drawing through a slightly smaller die without using an interior plug or mandrel.

Relation of Grain Size to Temperature

2. *Grain size increases as temperature increases.*

Curves in Fig. 9 and 11 show the grain sizes which include the minimum and maximum range likely to be encountered in commercial operations of all types. As previously mentioned, light gage strip for small articles usually performs best when it has grain size of 0.050 mm. or under. Heavy gages, usually because of severity of operations, are over this — typical being an Army Specification 57-173B for cartridge brass disks, requiring gages up to and including 0.400 in. to have grain size of 0.055 to 0.115 mm., and thicker gages to have grain size of 0.075 to 0.150 mm.

(Grain sizes over 0.200 mm. are rarely produced in ordinary work.)

Accordingly, deep drawing ability corresponds roughly to the grain size. The larger the grain size the deeper the draw obtainable. Some exceptions and qualifications to this statement will be given later.

Referring specifically to Fig. 9 and 11, it will be noted that considerable softening occurs before the recrystallization temperature is reached, which is somewhere around 750° F. These curves are typical of alloys annealed after a considerable amount of cold work; note for example the sharp drop in tensile strength shown in Fig. 9 for cartridge brass annealed at 550° F. after cold rolling six numbers

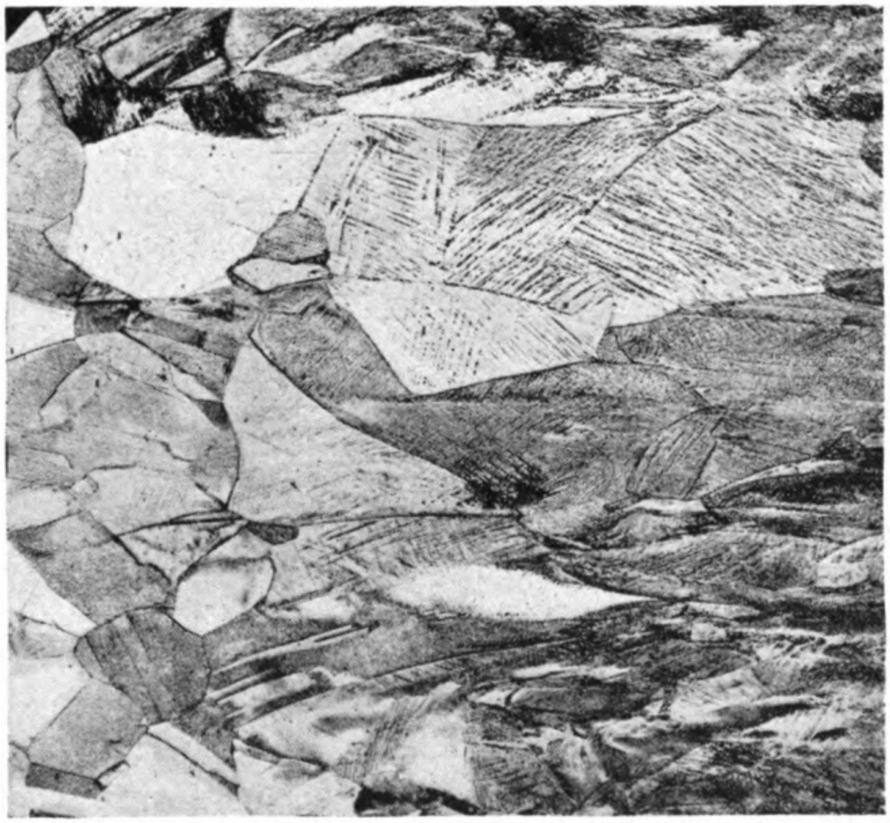

Fig. 17 — Rapid Transition From Light to Heavy Cold Work Near Indent in Cartridge Case Head, Originally of Large Grain Size (About 0.200 Mm.). Grain size control of such articles is next to impossible, as the cold worked material would recrystallize to a small grain size under certain conditions, whereas the large, unstrained crystals would remain the same size as they are

hard. (With electrolytic copper such a drop is even more sudden, unalloyed copper being much more sensitive in this respect than the brasses are.) Hence, in estimating the previous treatment of a sample of 70-30 brass of unknown manufacturing history, low hardness and strength in the tensile test, together with distorted, work hardened crystals under microscopic examination, most likely would indicate an anneal within the range between softening and start of grain growth.

In commercial practice, however, it is difficult to obtain physical properties by annealing between the range of "cold worked" and "softened", for metal is usually annealed and

Table IV — Hardness Versus Grain Size for Cartridge Brass

Grain Size	Hardness	
	Rockwell F	Rockwell 30T
0.015 mm.	72 to 85	33 to 50
0.025	67 to 79	27 to 42
0.035	65 to 76	25 to 38
0.050	61 to 73	20 to 35
0.070	54 to 67	
0.120	50 to 62	

then cold worked to the required degree. As an example, in Fig. 8 a tensile strength between 65,000 and 90,000 psi. calls for 1½ to 7 B&S numbers reduction. In Fig. 9 the same tensile strength range is covered by anneals between 500 and 600° F., but the speed of softening is so great that it is nearly impossible to catch the required property on the "down slope" of the curve, with ordinary commercial equipment. It is done under certain definite conditions and with alloys other than 70-30 brass, but not always successfully even then, some metal becoming too soft. Therefore it is not practical to soften metal partially by annealing after it has been made too hard.

For physical properties commercially expected with varying grain size, a good standard is given in American Society for Testing Materials' Specification B36-42T for Alloy No. 6, as shown in Table IV. In variations incident to commercial operations, overlapping of tensile strength, apparent elastic limit and other properties is to be expected. Hence, use grain size for best control.

3. With a given amount of cold work, grain size after annealing will vary according to type of furnace equipment.

It goes without saying that annealing curves shown here are only guides for actual annealing practice. Every

furnace must be calibrated individually, especially as to

(a) Source of heat.

(b) "Temperature head" — that is to say, the excess temperature of gases, atmosphere or other heating medium over that temperature required to produce a given grain size.

(c) Cross section of parts or pieces of charge.

(d) Weight of charge.

(e) Time.

(f) Grain size tolerance required.

In the last analysis the amount of grain size control needed will determine the type of furnace equipment. Modern requirements of deep drawing have made it necessary for the brass mill to control grain sizes closely in the range between 0.010 and 0.050. For example if grain size 0.030 mm. were to be specified the mill can deliver 0.025 mm. minimum to 0.035 mm. maximum, a tolerance of $\pm$0.005 mm. from that specified. This requires furnaces capable of evenly distributing the heat throughout the charge and at such a rate that no part gets hotter, or stays hot much longer, than another.

Such equipment may be of two types — batch and continuous. In the former, a typical batch type furnace burns fuel in an outside chamber, the products of combustion being blown about and through the charge in continuous circulation. Control is such that a mean temperature head of 25° F. is achieved. Consequently, no part of the charge gets hotter than it should, regardless of cross section, weight, or placement. Time in the furnace is several hours.

The continuous type of furnace, on the other hand, carries a temperature head of 150 to 200° F. over that needed, and the metal travels through the heat zone continuously. Provision is made here also for circulation of atmosphere, although in a different manner. Time in furnace may be

15 to 45 min. This type of furnace is particularly adapted to tube annealing, while the batch type is adapted to coiled strip and other relatively dense and compact metal masses.

The types of furnaces just described illustrate the principles used for close grain size control. If such control is not needed, or this type of equipment is not available, then certain factors must be considered in more detail for calibrating the furnace. Unless heat is evenly circulated to all parts of the charge, the type of heat should be considered. If it produces hot spots, due placement of the heavier sections of metal nearer to it tends to smooth out the heating rate.* If the entire atmosphere is several hundred degrees higher than needed — that is, the furnace runs on a high temperature head — the metal cross section should be similar for all pieces in the charge to avoid uneven heating; all parts of the charge must be kept from becoming hotter than desired, or one portion exposed for a longer time than another. If this is not done, grain size will be larger than expected, since increasing time at temperature increases grain growth. Naturally, pyrometers should be used to detect temperature differentials.

Over-all annealing time will be affected by the weight of metal charged, as all know, because it takes longer for a furnace to bring a heavy load to temperature than a light load. However, the *effective* annealing time for brasses is only that at which grain growth proceeds, within commercial limits, and grain growth does not start until the recrystallization temperature is exceeded. Practically speaking, in the batch type furnace an average time of 40 min. for metal at temperature is enough, although heating time may be several hours. This gives sufficient time for complete recrystallization and grain growth to occur, yet not enough

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*This assumes that the section is not subject to cracking by differential expansion.

for excessive grain growth. As a rule, 30 min. to 1 hr. is enough time *at* temperature, once all the metal has been heated.

To reiterate, annealing time is composed of time to get the charge to temperature *plus* the time at which grain growth is proceeding.

In summation of the furnace variables affecting annealing, it may be said that changes in prior cold working, metal cross section, or metal weight charged must be compensated for in the heating schedule if consistent results are to be maintained.

Practical Control of Grain Size

The question may well be asked, "How much control over grain size must be exercised?" The answer is not without qualifications: "It all depends!"

The *minimum* grain size will usually be established by the cold working operations in the plant. Too small a grain size results in too much breakage in manufacturing. Perhaps the resulting physical properties for a small grain size are improper for successful fabrication of the job in the tools and equipment available; probably elongation is too low — though if the specification controls the tensile strength, this may be too high. Therefore, annealing conditions are established to produce the minimum grain size to meet these production needs, and are usually set at a slightly higher temperature than the absolute minimum for an adequate safety factor.

On the other hand, the *maximum* grain size will depend on more complex factors. First to be considered is the fact that the actual measurement of the average grain size becomes less accurate as the absolute value increases. For example, at 0.150 mm. some grains are considerably smaller than the average and some larger. Consequently, a toler-

ance of 0.050 mm. would not be excessive, as compared to ±0.005 mm. at 0.030 mm. average specified.

Control of maximum grain size depends on the cold forming operation on at least three counts:

(a) The larger the grain size the rougher the surface after working, especially if no "ironing" between tool surfaces is done, as at the end of a punch. "Orange peel" results, a condition which is nearly self-descriptive, the surface being rough, much as an orange skin. If the part is subsequently polished or a smooth surface is necessary, the smallest grain size that will work without breakage is preferred.

(b) Close control is indicated with certain types of operations. A large grain size will cause breakage just as too small a grain size will. We have had examples of deep drawing in which 0.030 mm. was too small, breakage occurring, and at 0.050 mm. breakage also occurred because metal was too soft to withstand the tensile pull. About 0.040 mm. was found to be ideal.

(c) If minimum hardness or tensile strength is required, then grain size cannot be allowed to become so large that these values fall below specification.

Consequently, the conditions of operation will determine the degree of grain size control needed, and each case must be determined in the light of all requirements. In any event, it is hardly economical to heat metal so hot as to produce very large grain sizes.

While much of the foregoing has specifically referred to strip, the raw material for cartridge cases, cartridge brass is used in rod and tube form for many articles requiring forming of some description — for rod intended for cold extrusion or cold heading, and for tubing for bending and flanging, to which these principles apply.

Chapter III
Manufacture of 20-Mm. Cartridges (Condition of Metal During Processing)

TO POINT-UP these principles stated in the preceding chapters, the following will examine the processing of a 20-mm. cartridge case, a very fine example of deep drawing.

At the outset it might be well to state that all brass cases are processed in the same general way. However, since proportionate dimensions of base thickness, side wall thickness, length, diameter, and amount of taper vary from caliber to caliber, and even vary for guns of different design yet of the same caliber, these individual characteristics of the various designs will modify the sequence of production operations. Even on a single design, plant-to-plant production lines will vary because of differences in equipment available to do the job, as well as the personal preference of production staffs. For example, the extent of automatic handling tends to increase as the caliber decreases (as would be expected) particularly in feeding to presses and base turning machines.

Regardless of these variations, all cartridge case manufacture is concerned with cupping a disk of proper gage and grain size at the start and then, by successive draws and re-draws with appropriate anneals, elongating the original cup into a hollow cylinder with one end closed in a

dome shape. A case which is short in length compared to its diameter will be done in two or three draws, and a long one in, say, five. The heading operations are nearly the same for most designs, and the neck will have either a gradual taper or a relatively sharp diminution (the latter exemplified by the 20-mm. case about to be described in detail). The base will be finish-turned — either for accurate size and contour when a lip is present (ammunition for non-automatic, large caliber guns, as an example) or, in addition, for an extractor groove in small caliber, semi-automatic ammunition. (The lip or extractor groove engages a finger which removes the spent case from the chamber.) Mouth annealing is required to produce metal soft enough for crimping onto the projectile; for protection against stress corrosion cracking (season cracking) a final relief anneal is used.

Requirements for Cartridge Cases

There is much similarity also in the physical properties of various sizes of cases. Details will again vary because of individual needs of different types of ammunition. Cartridge cases all act as containers for a primer plus a propellent charge and, in "fixed" ammunition, as holders for the projectile. The general properties demanded of the metal will vary in different parts of the case, but adequate strength to prevent bursting or similar failure is an elementary requirement, together with equally adequate elastic properties to return to shape after firing stresses are released. Sufficient ductility is needed to avoid brittleness.

Specifically, the body of the case must expand almost instantly, by the pressure of burning powder, enough to take up the clearance between it and the gun chamber, thus sealing off gases from leakage back through the breech.

This property is known to ordnance officers as "obturation". The gun itself expands due to the imposed stresses, and the cartridge case must follow up, maintaining a gas-tight seal. After the projectile has left the gun, and the case is ready to be ejected, it must return nearly enough to its former size so it may be removed freely and quickly. This requirement means an elastic limit sufficiently great so that too much permanent set doesn't occur during the expansion. The mouth must be at least strong enough to hold the projectile during the time of storage and transportation, and tightly enough not only to keep them together but also to protect the powder from the elements — yet at the moment the projectile leaves the breech chamber the mouth should let it go without cracking. Truly, a versatile metal is needed!

There are other requirements which aren't part of the present discussion, such as elastic modulus, non-sticky surface when hot or cold and in contact with gun chamber, excellent corrosion resistance for safe storage, proper size and tolerances. It might be remarked, however, that tolerances are a particularly important subject, in view of the high order of interchangeability needed. Any one of millions of cases must fit any one of thousands of guns for jam-free operation. This explains the necessarily thorough gaging and inspection the Ordnance Department gives them.

All in all, a cartridge case, though it may not be as spectacular as an aircraft engine, is in its own way a pretty precisely controlled engine of destruction. Just how precisely controlled may be deduced from a statement by Brig. Gen. James Kirk, in 1944 chief of the small arms branch of the U. S. Army, Ordnance Dept. He quotes representative figures from one group of soldiers that fired 414,715 rounds of caliber 0.50 machine gun ammunition in a 25-day campaign. In this period, only six stoppages occurred, chargeable to gun or ammunition failure.

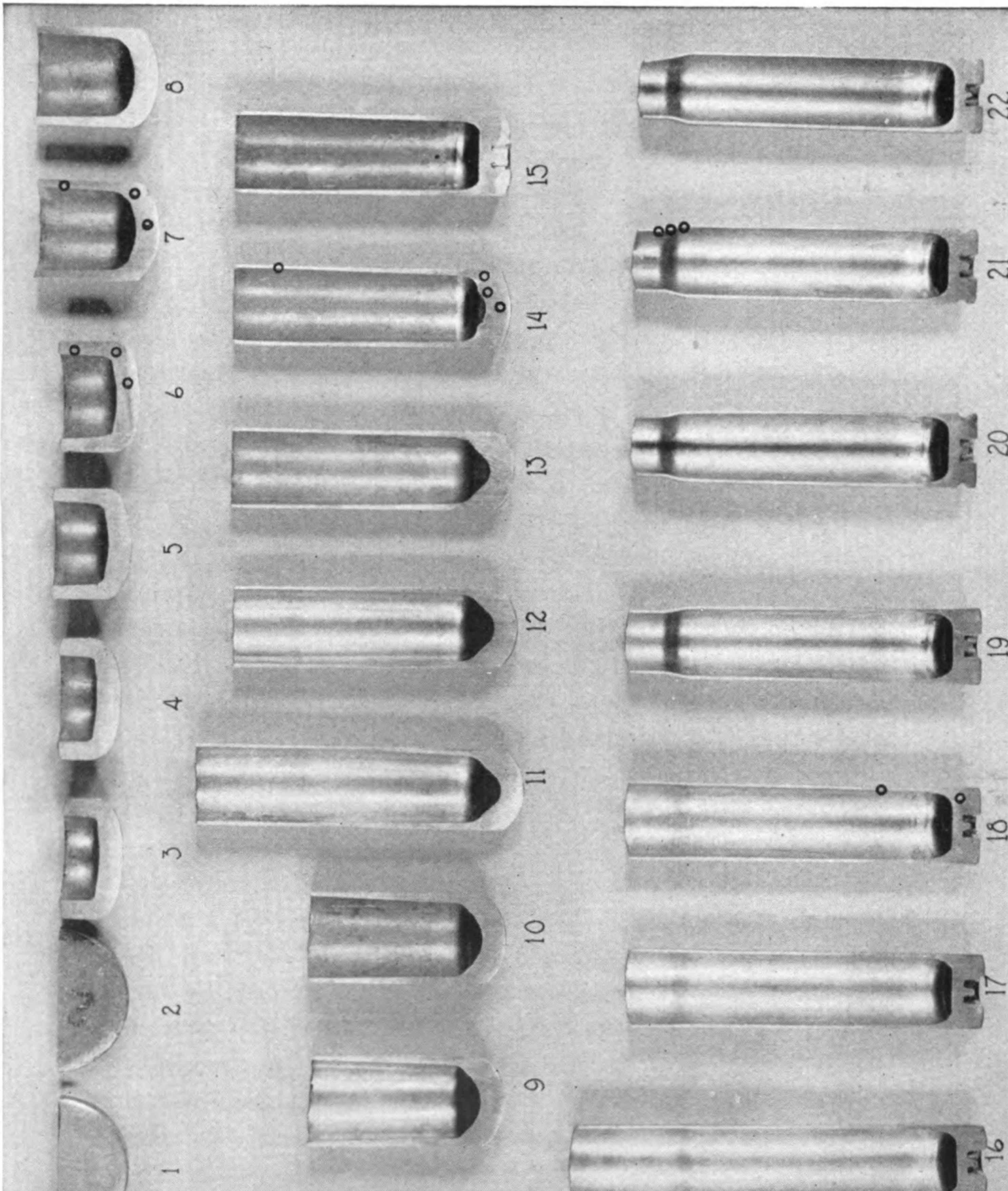
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Fig. 18 — Various Stages in 20-Mm. Case Production, as Listed in Table V. Locations of micrographs in this chapter are shown by small circles

Sequence of Manufacturing Operations

Turning now to the manufacture of a 20-mm. cartridge case, the operations shown are not necessarily exact for any one manufacturer — for reasons explained previously — but are intended to show the overall picture. The layout of samples, as in Fig. 18, is numbered by the piece; they are shown about one-third size. For the operations sequence refer to Table V, but note that various cleaning operations are not listed. Micrographs are at 75 diameters.

Table V — Sequence of Operations

Samples No.	Operations
1 and 2	Blank; anneal
3 and 4	Cup; anneal
5 and 6	First draw; anneal
7 and 8	Second draw; anneal
9 and 10	Third draw; anneal
11 to 15	Fourth draw; trim; anneal; re-strike; indent
16 to 19	Fifth draw; trim head; neck anneal, taper
20	Machine extractor groove
21	Mouth anneal
22	Finished case, stress relieved

Referring particularly to the layout in Fig. 18, it will be noted that the cupping and first three draws serve generally as preparatory operations. These are shown in Fig. 18 as samples No. 3 to 10 inclusive. The finished case (sample No. 22) has a light wall gage as compared to the original blank thickness. Since a relatively large mass of metal must be provided at the base, the original blank must be of sufficient size to do this. Consequently, these preparatory operations are not elongating the part much, but are

rather thinning the side wall of the cup, and retaining the heavy bottom needed to finish the head.

There is, necessarily, a limitation on the reduction that can be made on the wall's thickness with each operation, not only because great reductions make metal considerably harder and workability drops, but because the tools also have some limitations. The 20-mm. case takes a greater number of initial draws before pulling out to length than do some of the larger calibers with smaller ratios of height to diameter. Also, more metal is needed at the bottom for the peculiar base design.

The fourth and fifth draws (samples No. 11 and 16 in Fig. 18) pull the length out to that required to produce the finished case, allowing for adequate trim. Re-striking and indenting operations No. 14 and 15 are again more or less peculiar to this cartridge and are tied in with the base design. Metal doesn't always flow as predicted, and die shapes many times must be varied on the job to produce the flow which later will give the finished contour needed. At the same time there are physical property requirements of the base which often necessitate additional operations; otherwise, the amount of cold working would be so slight as to leave the metal in nearly the annealed condition. (See further discussion of this point when describing the micrographs.)

The tapering operation No. 19 in this line-up reduces the diameter of the case, but some cases are truly tapered without the sudden "necking down". The latter operation may be accomplished without an internal mandrel or punch, which is used on the regular draws.

(Punches for the first to third draws will usually be roughed at the end by grooving or other means to prevent metal from flowing sidewise under them. The bottom of the cup thus stays thick. Dies and general tool design are mat-

ters for discussion which, though exceedingly important when it comes to performance of a metal, are not without considerable individual opinion and will not be expanded upon in this book.)

Heading* may be done in one operation on a one-stroke press. Final machining may include drilling the primer hole, although this operation is not shown in Fig. 18. In some types of ammunition this is followed by drilling and tapping inside the head for subsequent insertion of hooks for powder bags.

Cleaning — While cleaning is not strictly a branch of metallurgy, it should be mentioned that best drawing requires clean surfaces. Drawing compounds which carbonize at annealing temperatures, such as certain oils or soaps, should be removed prior to heating. Such carbon products are very nearly impossible to remove, once on, and are destructive to tools. Cleaning of surface oxide after annealing is obviously necessary, and the solvent must be of a type to leave unetched surfaces, etching being one cause of metal breakage, for the surface friction, die-to-work, becomes too great.

Microstructure After Early Draws

In the course of a study of 20-mm. case fabrication, each of the samples in Fig. 18 was examined for microstructure. Since the micrographs of some sections are practically identical with others, only certain typical ones will be shown here.

The blank, cup and first three draws show generally similar grain sizes. This blank was annealed, but many

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*"Heading" produces the lip which will engage the extractor finger in the gun, or presses the base to a final desired contour and dimension, suitable for the machining of base to required tolerances.

cases, especially for small arms, are blanked from annealed metal and then cupped without further annealing. Grain sizes for these rather drastic initial operations are kept large — 0.090 to 0.150 mm. on the average, and for reasons developed in the preceding chapters. Large grain sizes are acceptable since orange peel surface is not to be feared, surface polishing is not required, and neither is maximum ductility necessary for these intermediate operations. No hold-downs are employed in drawing, so there is no danger of breakage due to this cause — excessive tensile stress.

Typical of conditions existing during these operations are micros of the base, wall and corner of sample No. 6, which is the first draw annealed (see Fig. 19, 20, 21), and of sample No. 7, the second draw (see Fig. 22, 23, 24). After

Fig. 19 to 21 — Microstructure of Annealed Cup After First Draw, Step No. 6 of Fig. 18. Metal has characteristic large grain sizes (approx. 0.120 to 0.150 mm.) with typical twinning. Magnified 75 diameters

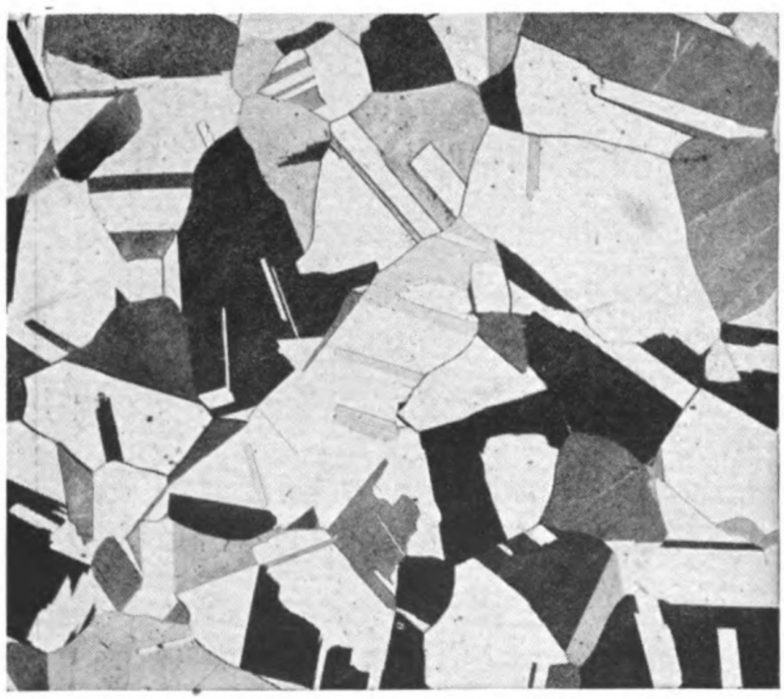


Fig. 19 — Center of Base

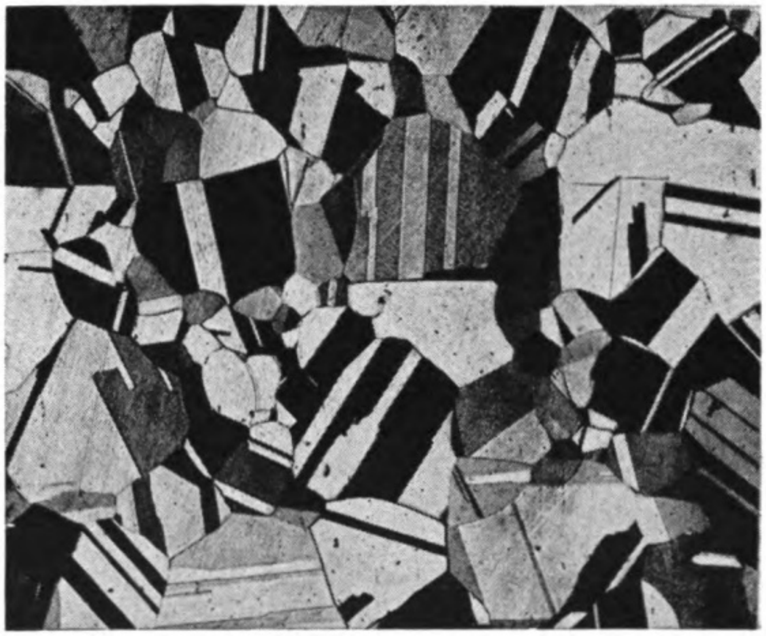


Fig. 20 — Side Wall

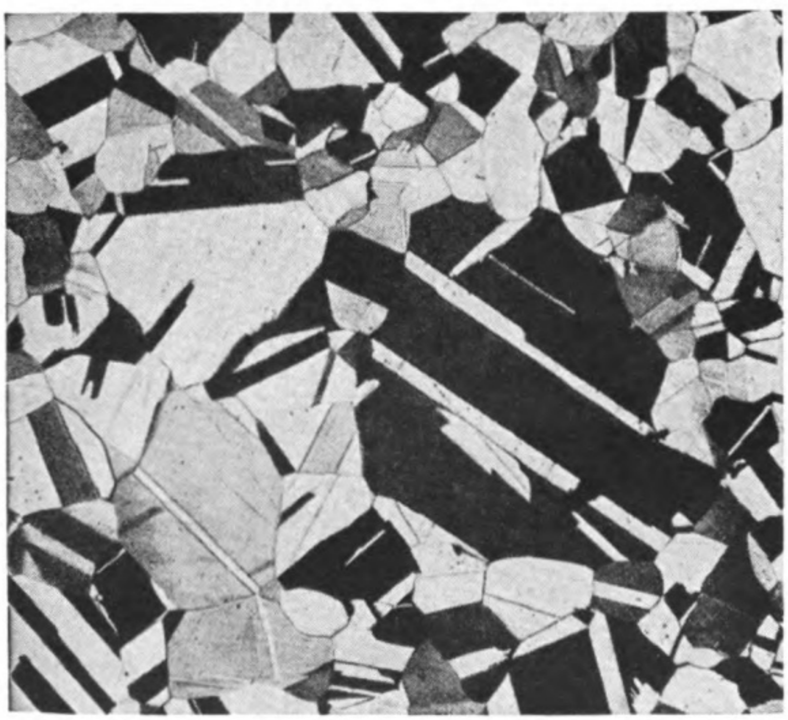


Fig. 21 — In Corner

the second draw the wall (Fig. 23) shows typically cold worked structure, but the base shows no deformation of any consequence (Fig. 22). Both of these are typical of samples up to and including the fourth draw.

After annealing the wall tends to have a smaller grain size than the base. In view of what was said in the earlier chapters, this is to be expected since recrystallization requires previous cold working or, contrawise, it was stated that grain growth does not occur readily upon re-annealing. We have the latter condition in effect here because the base has not been cold worked; it is substantially metal that has been annealed more than once. The corners are

Fig. 22 to 24 — Microstructure of Case After Second Draw, Not Annealed; Step No. 7 of Fig. 18

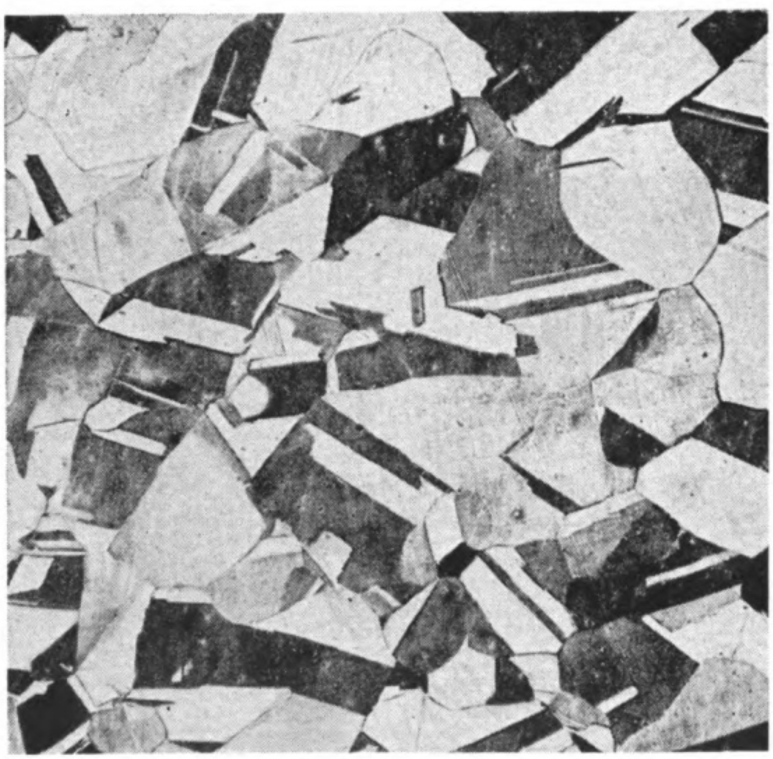


Fig. 22 — Center of Base, Showing no Evidence of Strain Lines or Deformation, Hence no Cold Working of Any Consequence Except Perhaps at the Very Surface of the Metal

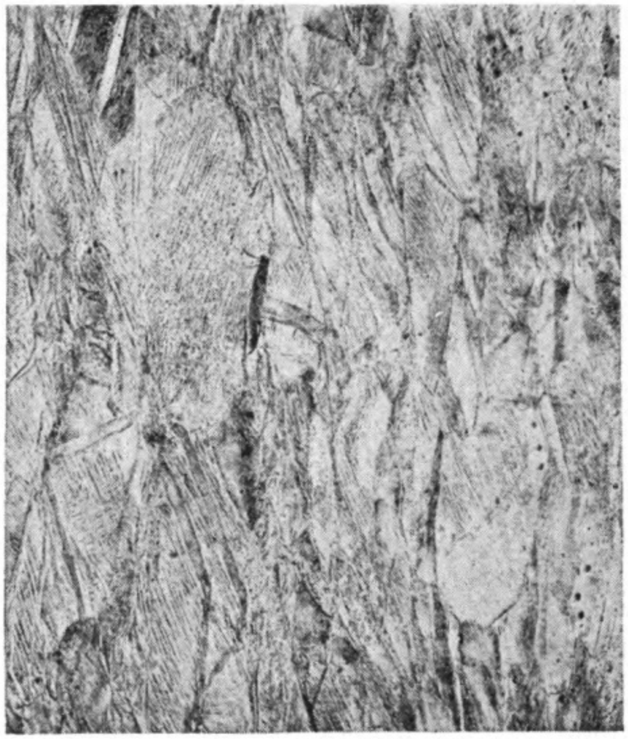


Fig. 23 — Side Wall Having Severely Cold Worked Metal

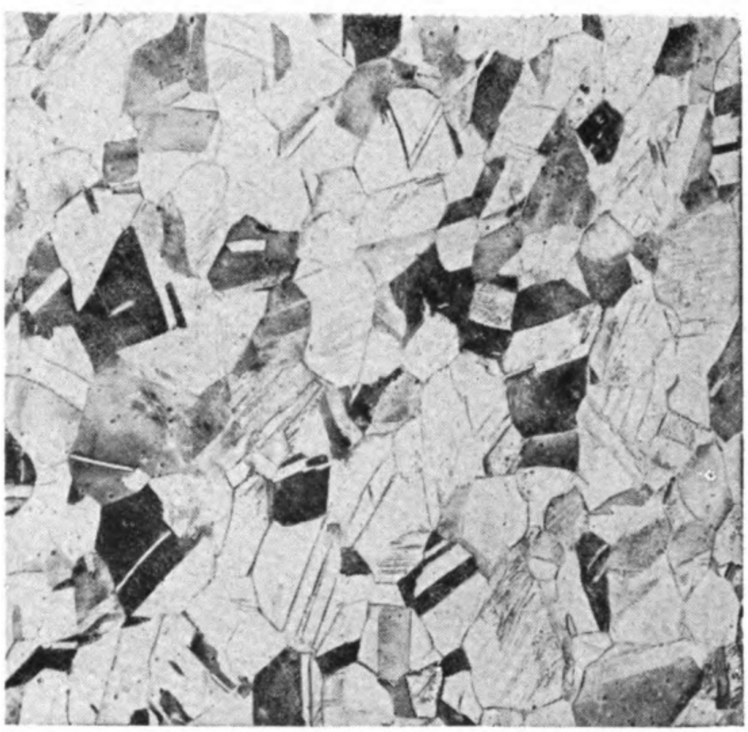


Fig. 24 — Corner of Base, Showing Slight Evidence of Strain Lines

lightly cold worked, since some flow occurs at the junction of the punch radius and punch side.

The base of any case must be formed to the final desired shape, as well as have strength enough to stand pressures of burning powder and to hold the primer tightly. The base of this case is strengthened by cold working occurring during the indenting operations, as well as by the pressure of re-striking. For example, in Fig. 25 and 27, the center of base and side wall corner, respectively, the annealed structure is shown, whereas Fig. 26, the shoulder near the inside, shows cold worked metal. Cold working after the last anneal has evidently been confined to the region near the last mentioned micrograph.

Fig. 25 to 28 — Microstructure of Representative Locations, Shown in Small Circles on Sample No. 14 of Fig. 18, of the Cartridge Case Re-Struck After the Fourth Draw and Anneal

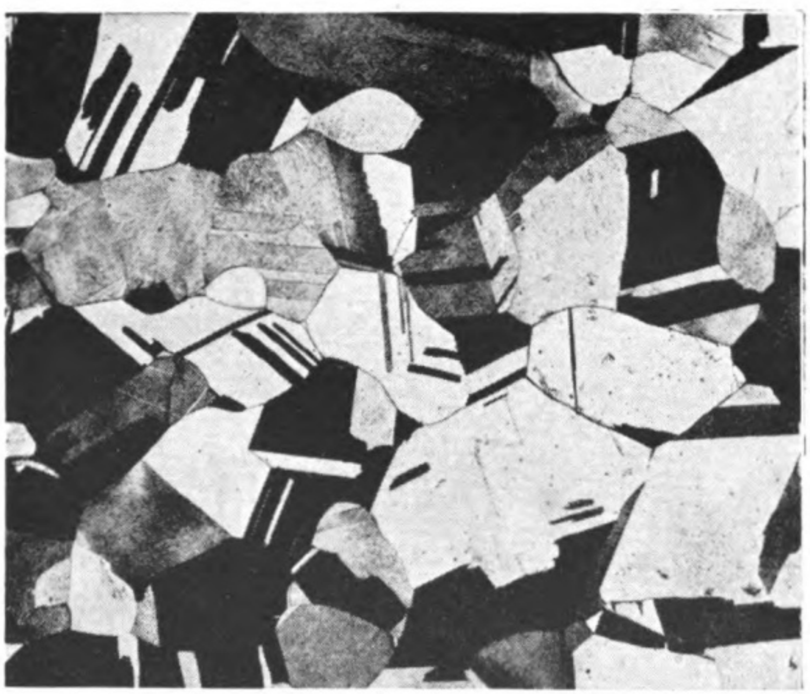


Fig. 25 — Center of Base Has Annealed Structure, Grain Size About 0.150 Mm. Average

Fig. 28 — Side Wall Not Worked; It Has an Annealed Structure, Grain Size About 0.100 Mm.

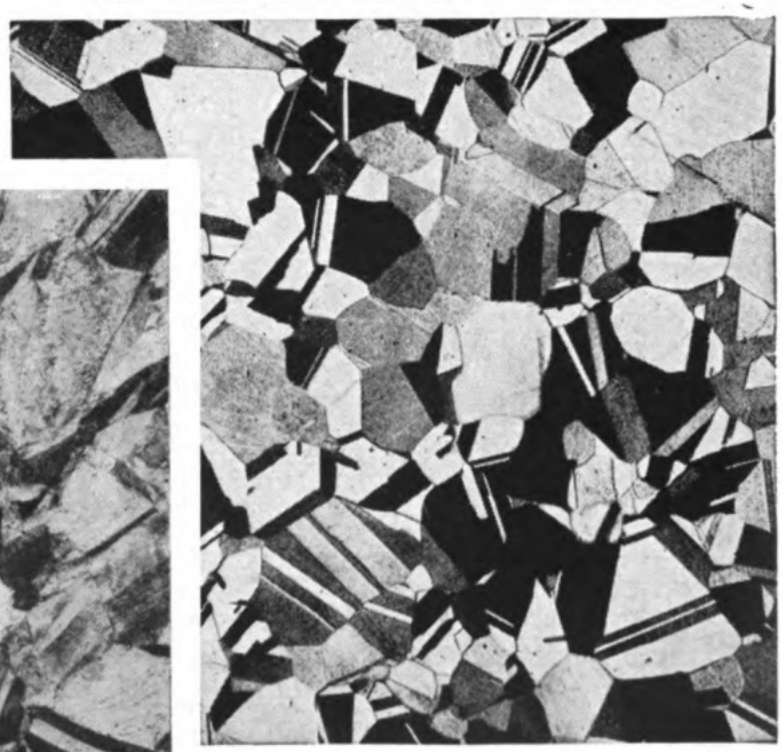


Fig. 27 — Corner of Base Has Same Structure as Side Wall

Fig. 26 — Structure of Shoulder on Inside; Crystals Are Distorted by Re-striking Operation Which Hits Only Part of the Base

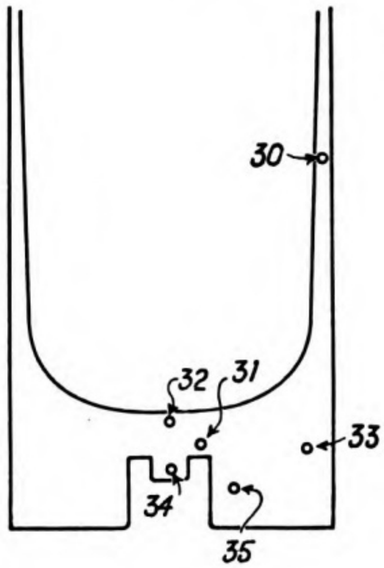


Fig. 29 — Location of Micros Taken From Fifth Draw, Headed, Step No. 18 of Fig. 18

As compared to this, refer to the micrographs, Fig. 30 to 35 inclusive, showing the condition of the cartridge at and near the base after all the cold working operations have been performed on the head and side wall. The side wall Fig. 30 and a greater portion of the base structure are now typically cold worked in appearance. The last or fifth draw must provide enough cold work in the side wall to raise the tensile strength and elastic limit up to the specification established by the Army or Navy according to the particular needs. This is an illustration of the principles taken up in the prior discussions in this book and of the physical

Fig. 30 to 35 — Micros Located in Fig. 29; Case After Fifth Draw, Headed

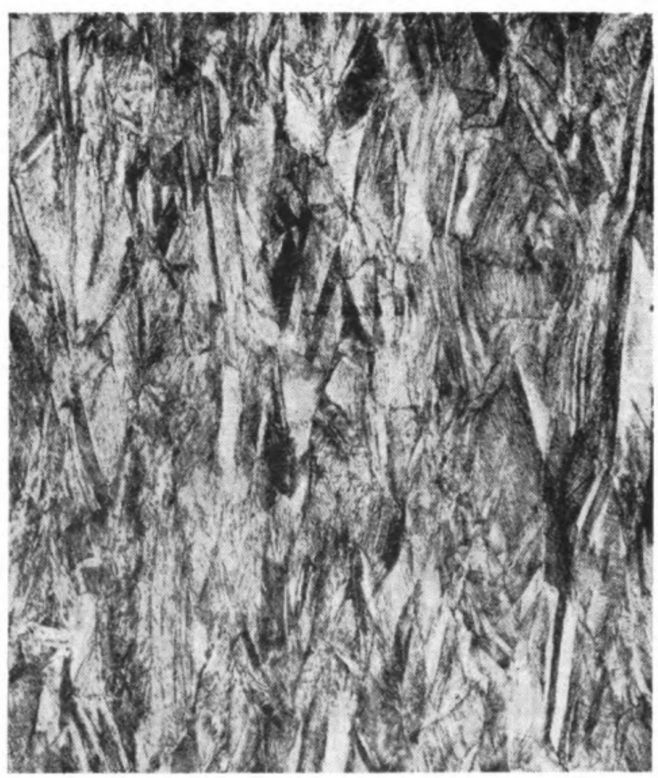


Fig. 30 — Side Wall, Extensively Cold Worked

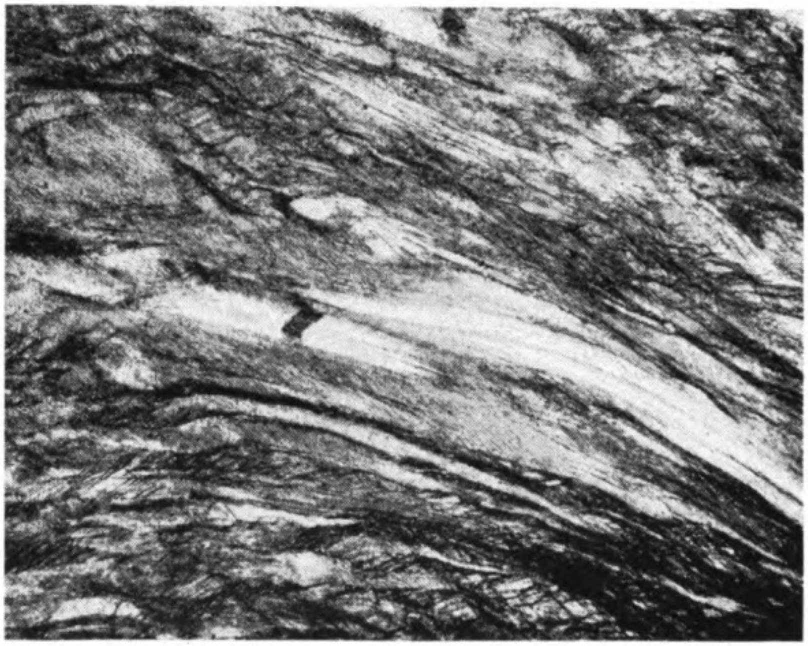


Fig. 31 — Above Groove in Primer Cavity, Showing Severely Cold Worked Metal. A considerable flow of metal is typical in this location

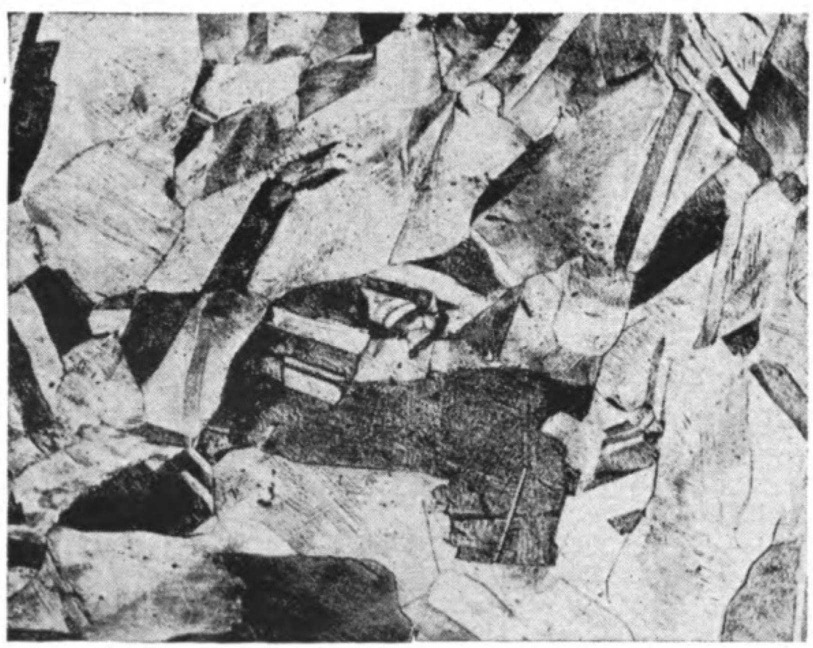


Fig. 32 — Center of Base Has Been Slightly Deformed and Shows a Few Strain Lines

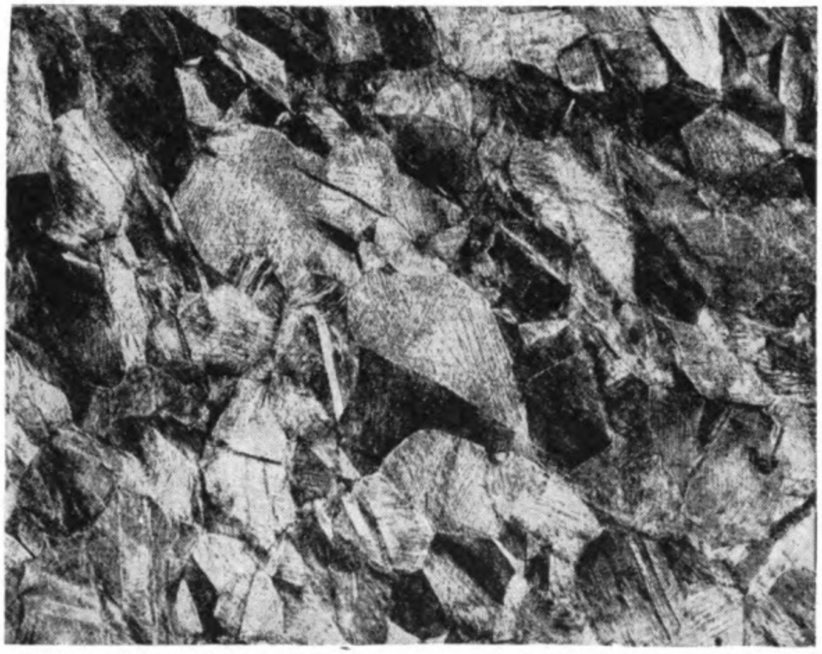
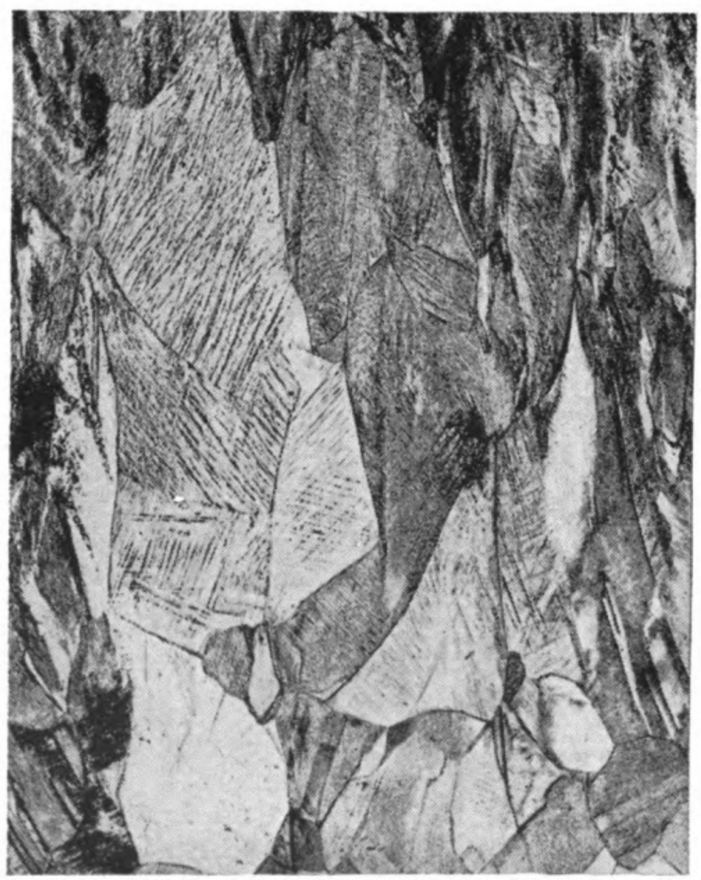


Fig. 33 — Corner of Base Has Received Some Cold Work and Shows a Large Number of Strain Lines But Not Much Deformation

Fig. 34 — Pimple in Primer Cavity Shows a Range of Conditions From no Cold Work at End to Very Severe Cold Work at Neck



property curves in which it was pointed out that increasing the cold work (by the reduction in area or B&S numbers) is the only way to increase the tensile strength of non age-hardening copper-base alloys. The micrographs quite graphically show also the varying structures typical of the varying amounts of cold working.

Fig. 35 — Shoulder Is Cold Worked and Contains Some Evidence of Directional Flow

In order to reduce the diameter at the mouth of the case, a cold working operation known as tapering is used. However, the case wall may be cold worked already to a degree such that there is not enough remaining ductility to permit the shape change. A prior neck anneal is then used for only such portion of the open end as will be affected by the reduction in diameter.

Following this tapering to size, the mouth is annealed — perhaps by gas flame or salt bath — an operation usually

designed to produce a very small grain size. Such a small grain size is indicative of metal with considerable ductility, yet when it is cold worked by crimping onto the projectile in the shell loading plant the strength is sufficient to hold it tightly. Even if more severely cold worked metal would turn over without cracking, there are instances in which it would be of no value. For example, the elastic limit might be so high the amount of movement during crimping would not be enough to deform it permanently — there is some "spring back". Figures 36 to 38, showing micros made after the neck anneal, taper and mouth anneal, indicates what has happened. The mouth (Fig. 36) is now very finely

Fig. 36 to 38 — Structures of Finished Case; Step No. 21 of Fig. 18

Fig. 36 — Mouth Has Very Fine Crystal Size, Less Than 0.015 Mm. Prior to mouth anneal, it was identical in appearance to Fig. 37

recrystallized, though prior to mouth annealing it was cold worked, like the next lower section, the neck, Fig. 37. Finally, at the shoulder (Fig. 38) strain lines across the crystals indicate light cold working — in fact so light that the grain size resulting from the neck anneal could readily be determined.

Fig. 37 — Neck Is Cold Worked, Typical of Average Reductions

The final operation of relief annealing does not change the crystal structure, and any micrographs in figures relating to the fifth draw or mouth anneal are duplicated by those taken on the finished case.

In summation, the mouth is left in a lightly annealed state (0.015-mm. grain size range in Table III of Chapter I),

the side walls cold worked to a considerable degree and parts of the base are still soft but other parts of the case are severely cold worked.

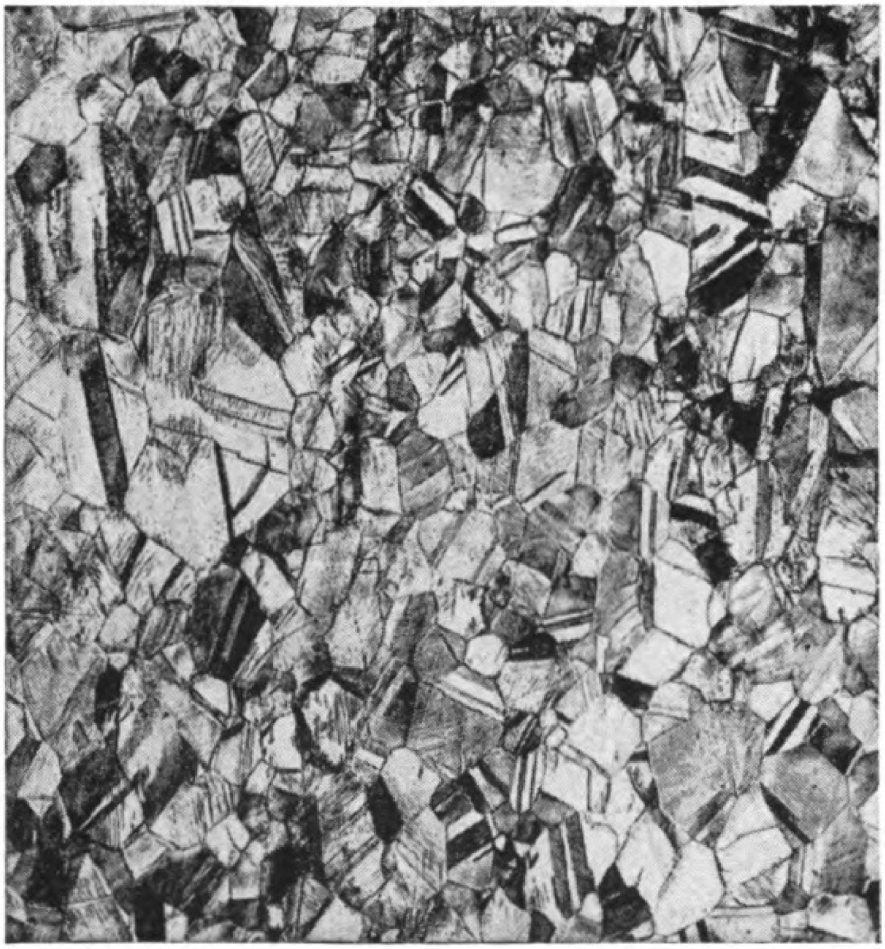


Fig. 38 — Shoulder Is Slightly Cold Worked (Typical Micro)

Fig. 39 — Muntz Metal (Nominal Analysis: 60% Copper, 40% Zn) Etched With Ferric Chloride, Which Darkens Beta Phase But Does Not Attack Alpha Phase

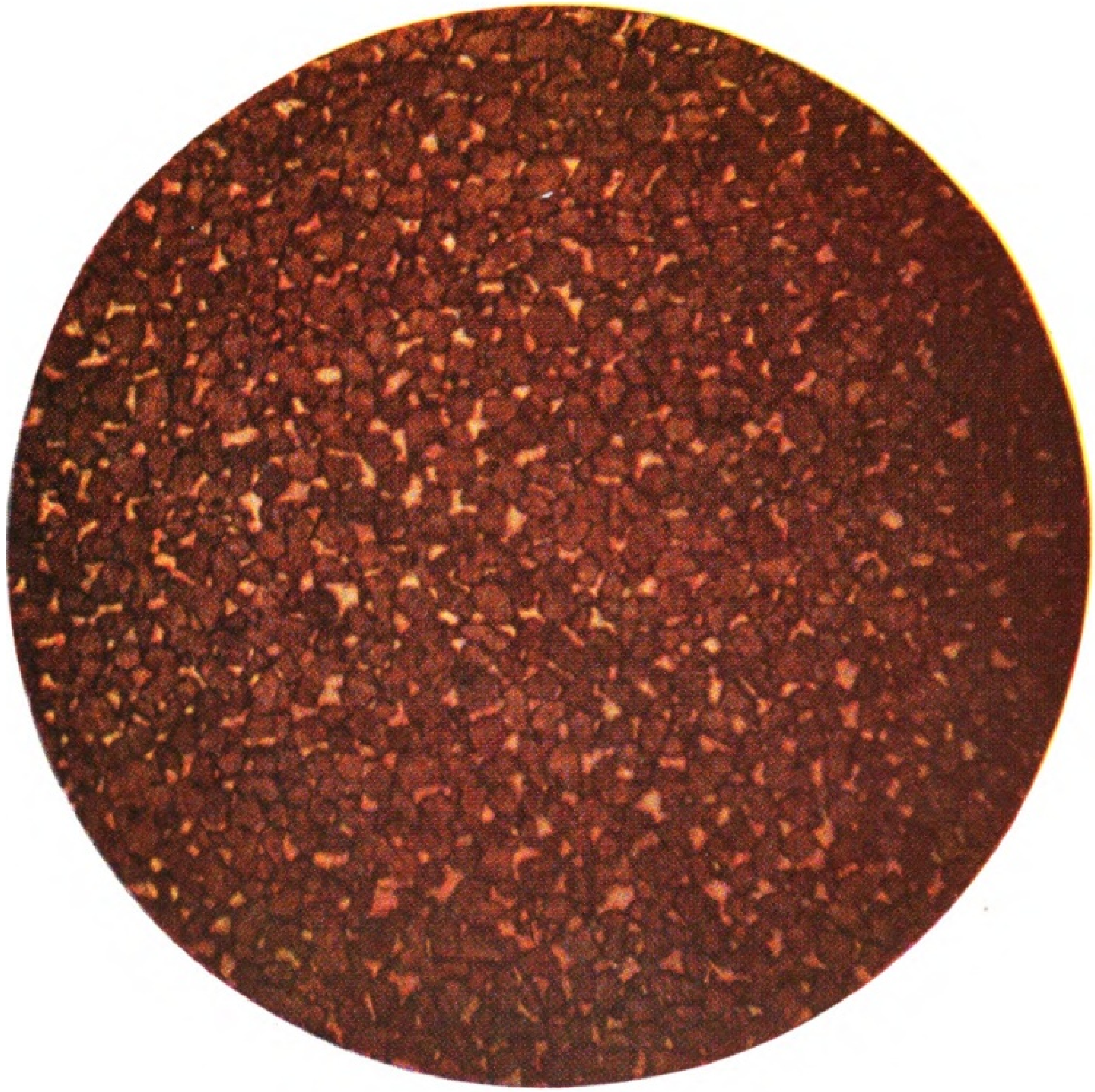


Fig. 40 — Muntz Metal. Same Sample as Above Etched With $NH_4OH + H_2O_2$ to Show Beta Phase Lemon Yellow. Color photography by R. D. Destito; Samples prepared by W. Jenks; All magnified 75 diameters

Chapter IV
Effects of Chemical Composition

UP TO NOW the discussion of cartridge brass in preceding chapters has dealt only with the physical properties of the alloy, on the assumption that chemical composition would not affect the cold working and annealing relationships. As far as commercial material is concerned this assumption is substantially correct, since mill control systems, specification and processing requirements tie down the chemical variations to close limits. It would be only an inadvertent shipment of off-analysis material which would upset the properties shown in the previous articles. It is the purpose of this chapter to show the control of elements necessary in the brass mill and the reasons therefor, as well as to indicate the advantage of close control of scrap in the consumer's plant.

Regarding the consumer's problem first: Any brass mill must use, for economic reasons if no others, considerable scrap either of its own making or purchased from its customers. (In some alloys, metallurgical reasons may prevent such use, but it is not true with cartridge brass.) Because of this need for scrap, it necessarily follows that its analysis must be accurately known, along with impurity limits, if specification and other requirements are to be met. Brass mills buy their scrap with this need in mind, with

regulations on source, type, freedom from oil and impurities, and other considerations. Since the price paid for it will vary ("clean heavy" scrap for instance being the highest and most desirable), it is to the advantage of any *consumer* of copper alloys (and producer of scrap) to keep different analyses separated within his plant, free from steel scrap, oil, and dirt, unless the monetary return from his gleanings is so small as to eat up all the cost of segregation and handling. Mixed scrap and scrap of unknown composition is usually considered fit only for the refinery, where it is smelted into pure copper. Such scrap has a limited market value as shown by an examination of published schedules.

The brass mill exercises close control of impurities such as iron or lead, as well as of the main metals copper and zinc, not only because cartridge specifications require it, but also because some impurities prevent successful manufacture, while others hinder it to a degree which greatly reduces efficiency. From the consumer's standpoint, there are few impurities which would cause trouble and which would not, at the same time, prove objectionable to the brass mill. Therefore, means for scrap segregation and melting-room control of scrap and virgin materials are a regular part of the operations of brass making. Systems are established to segregate own mill scrap at point of origin for subsequent return to scrap storage, which systems are tied in closely to identification procedures regularly employed during production of material destined for customers' use. Considering the hundreds of alloys and forms normally made in one plant, some such system is absolutely necessary.

Melting charges may be controlled by the chief chemist or similar responsible person, who actually designates the amounts of various grades of scrap to be supplied to each

furnace from the weigh room. Charges will be made up according to the scrap available, together with some virgin or mill copper scrap, if necessary, and zinc of the correct grade. At the same time the chief chemist will probably have theoretical custody of finished billets, cakes, extrusion blooms, and other heavy intermediate products, until his analyses are completed, at which time he will either send them to the fabricating mill — or reject, if off-analysis.

Control of raw materials other than scrap is also necessary — mostly on zinc, but also on special alloys for addition agents to materials other than cartridge brass. Zinc is purchased by "grade", as established in Specification B6-37 of the American Society for Testing Materials. Analyses are given in Table VI for reference, and should be kept in mind in any discussion concerning the effects of lead, iron and cadmium. The grade of zinc which will be used depends on the specification limits on impurities, how much dilution there will be by scrap or copper addition, and what method of processing the brass mill intends to employ.

Table VI — A.S.T.M. Specification B6-37 for Slab Zinc

Grade	Lead, Max.	Iron, Max.	Cadmium Max.	Sum of Lead, Iron, Cadmium, Max.
Special high grade	0.007%	0.005%	0.005%	0.010%
High grade	0.07	0.02	0.07	0.10
Intermediate	0.20	0.03	0.5	0.50
Brass special	0.60	0.03	0.5	1.00
Selected	0.80	0.04	0.75	1.25
Prime Western	1.60	0.08	....	....

As far as the fabricating methods in the brass mill are concerned there are four of major interest: *(a)* Casting into shape required for subsequent processing, *(b)* hot working or rolling for cartridge case strip, *(c)* cold working

or cold rolling, and *(d)* annealing. There exist impurities which can upset normal procedures for each of these processes, some more than others. However, the most common or serious effects are noticed in the hot or cold fabrication and annealing and are due to a relatively few common contaminants.

As an example, the newer brass mills rely heavily on hot rolling for "breaking down" castings (ingots or slabs) for subsequent cold finishing and annealing. The presence of a small amount of lead produces hot shortness — that is to say, at the worst the casting crumbles, or at the least edge cracks appear when roll pressure is applied. Antimony tends to produce cold shortness, one typical effect being lengthwise splitting down the middle.

The most frequent effect of unwanted impurities, considering the number of elements behaving similarly, is suppression of grain growth. Phosphorus, iron, chromium, nickel — to name a few — are quite powerful in this regard when present even in small amounts. Grain growth suppression is important from the standpoint of annealing schedules, which are established to produce certain grain sizes. The need for correlation of cold working and annealing has been accented in previous chapters, but impurities which throw off balance the normal relationships are just as bad as no correlation at all. In actual practice, for example, high iron will produce a grain size smaller than expected with the cold working plus annealing time and temperature ordinarily in vogue. (In passing it might be said that for certain uses of electrolytic copper, the elements silver and cadmium are deliberately added to increase the annealing temperature — that is, to suppress grain growth.)

As for specific effects: Changes in copper content in cartridge brass are not serious as far as fabrication is con-

cerned, except in very severe cupping jobs, wherein copper over 70% seems to eliminate edge cracking. The usually specified range of 68.5 to 71.5% copper (31.5 to 28.5% zinc) is not within a border-line area in the equilibrium diagram (see Fig. 41). There are commercial alloys either side of this range which are regularly used for hot and cold working, although in Chapter I we have shown that optimum properties occur at the 70-30 composition. Further exam-

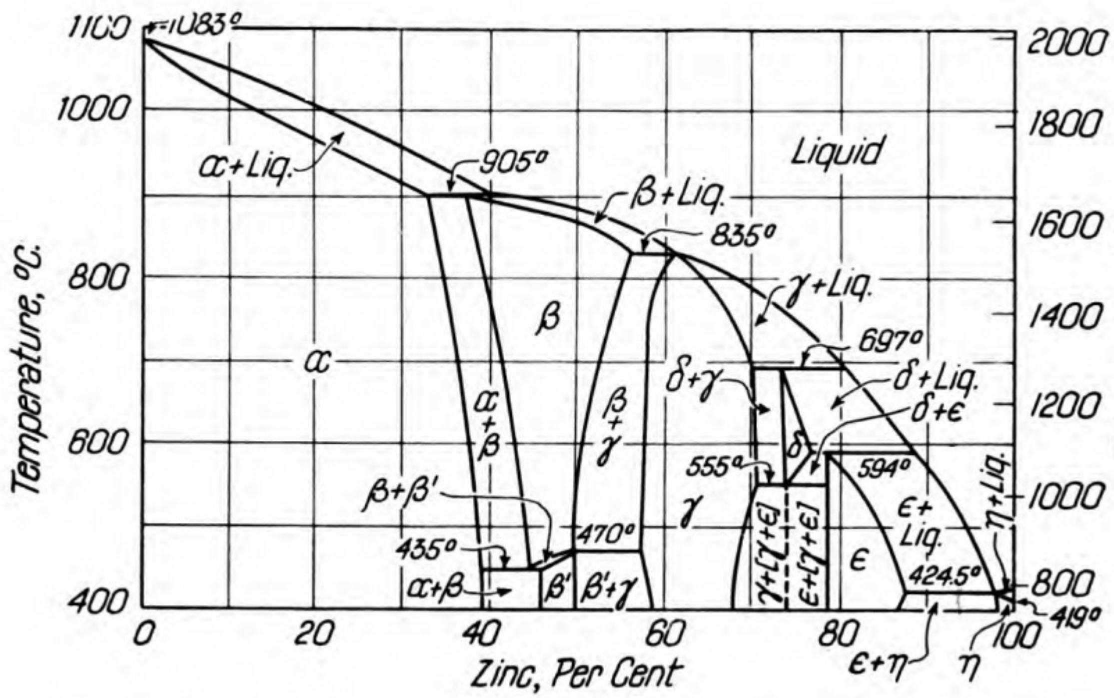


Fig. 41 — Equilibrium or Constitutional Diagram of the Copper-Zinc Alloy System, According to Phillips and Brick

ination of the equilibrium diagram will show, however, that one cannot stray far from the 70-30 ratio. As 64% copper, 36% zinc is reached there is opportunity for the beta phase to appear and as copper approaches 55% (zinc 45%) beta brass preponderates. Beta brass is a fine hot working material, but very poor for cold forming, becoming brittle when cold worked less than 20%. The hot working characteristics of beta brass are made good use of in many alloys, either with or without lead, and used for extrusions

or forgings. Copper alloys with less than about 55% copper are not commercially useful — they are too brittle.

For metallographic identification, beta constituent appears lemon yellow when etched with standard ammonium hydroxide reagent, or is darkened with ferric chloride reagent. Color photographs are shown in Fig. 39 and 40.

The impurities lead and iron are the most frequently mentioned in specifications as being limited in their allowable maximums. As an example, Army 57-173B (Amendment 7 of Feb. 20, 1941) "Disks — Cartridge Brass" places limits of 0.070% max. for lead and 0.050% max. for iron. Other specifications are in close conformity. Aside from their undesirable effects — and probably because of them, too — their frequent occurrence in scrap and zinc makes it desirable to check them closely. A large tonnage of leaded brass (free cutting brass rod, forgings, and other shapes) is returned as scrap, and admixture in cartridge brass is a relatively easy occurrence. Iron, of course, may occur as tramp iron carelessly tossed into a scrap pile or coming from contamination at some stage of its processing when near steel fabricating operations. (Magnetic separators are used by the brass mill stock house wherever the scrap form permits.) Other elements may also appear in common every-day production, most of them from platings on plated ware, such as cadmium, chromium, nickel and tin plate. Plated scrap is not particularly popular for brass remelting, not only because the plate covers up the base metal and makes identification on color alone that much more difficult, but also because most of these plating metals are powerful in their effects and the quantities added to the melt are not subject to calculation. It should be remembered that brass practice is different from steel making practice in that no refining takes place during brass melting. The only impurities which are removed to any appreciable

degree are those high in their oxidizing power such as calcium, boron, phosphorus and, to a lesser extent, aluminum. Actually all sorts of precautions are taken to prevent the oxidation of zinc in the alloy, such as the use of charcoal blankets on the molten bath.

Cartridge brass may contain many common impurities. The following discussion of these is made alphabetically rather than upon a basis of relative importance:

Aluminum — Scrap aluminum is not a likely source of contamination. As a rule its re-sale value is high, which prompts proper sorting; also its color is foreign to most brass making establishments. Its possible source, however, is from plants fabricating some aluminum bronzes (5 to 11% Al) and aluminum brass condenser tubing (76% Cu, 2% Al, bal. Zn). It doesn't take much aluminum in cartridge brass, however — upwards of a "trace" — to produce a characteristic skin when melted, and which is quite apparent by a rough surface on castings. There are no adverse effects as far as hot working is concerned or cold working — even with 2% aluminum. However, annealing practice is affected; aluminum raises the temperature required to produce a given grain size — it is a grain growth restrainer, in other words.

Antimony becomes troublesome when fired cartridge cases are remelted in large quantities, the source being the primer material, apparently, which lodges on the inside of the case after firing. Mixed lots of fired cases have been found to contain about 0.007% antimony. The element has always been of ill repute in brass mills, probably because the effects tend to be cumulative when associated with lead, and influence the hot rolling as well as cold rolling properties. For hot rolling the limit is 0.01 to 0.02%, and for cold rolling 0.10%. Lead present in an amount less than this will accentuate the effects. It is worthy of note, however,

that in combination with tin in admiralty metal condenser tubes (71% Cu, 1% Sn, bal. Zn), amounts under 0.10% antimony are added for inhibiting dezincification.

Arsenic most commonly occurs in scrap from admiralty condenser tubing, where it also is used to inhibit dezincification. Arsenical copper may also be a source. It does not adversely affect hot or cold working when added in commercial amount (under 0.1% in admiralty and 0.3% in copper) but does affect grain growth. Its presence is denoted by smaller grain sizes than expected, which tends to lower ductility unless annealing temperatures are raised.

Bismuth — As far as the brass mill is concerned, bismuth can probably be classed as the bad boy of them all, and has been anathema as long as it has been recognized for its ill effects. Alloys containing it can be handled in cold working or in annealing if its presence is known. Since it rarely appears, routine checks do not catch it, but processing does. It has been shown that 1% bismuth can be handled by suitable annealing and cold working schedules, or by adding phosphorus. However, without precautions, as little as 0.05% will cause cracking in cold working, and 0.006% is considered by many to be excessive for maximum cold working properties. (In Army specification 57-173B, the maximum tolerance is 0.006%.) As for hot working, 0.006% is about the maximum tolerance, since it causes hot shortness, and is therefore highly important considering the large amount of hot rolling in the making of cartridge brass. At the same time "fire cracking" is also attributed to bismuth — that is to say, the cold metal cracks open when placed in a hot furnace without first preheating.

Cadmium — Other than as a plating material, cadmium-copper (1% Cd) is the common commercial source of cadmium in scrap, though it is a relatively minor quantity item. As to its effects, it is not clear exactly what happens.

In copper, it increases tensile strength and the annealing temperature and affects processing procedure by causing trouble in hot rolling due to cracking. In cartridge brass, some authorities claim that 1% cadmium has no adverse effect, but others believe as little as 0.05% may have a bad influence on deep drawing quality. In mill annealing, less than 0.25% promotes fire cracking after cold rolling.

Chromium — Solubility of chromium is limited in brass and (aside from its possible presence in chromium plated scrap) this limits the alloys containing it and its importance as a possible contaminant. Apparently no ill effects to working properties accrue when it does dissolve, but it does powerfully affect annealing temperatures, restraining grain growth. Chromium contents of 0.05% produce grain sizes of 0.020 mm. at 550° C. (1022° F.) whereas an alloy with no chromium under similar conditions shows a 0.060-mm. grain size. Iron adds to the grain growth restraint when present with chromium. Not all impurities contribute to this additive effect — for example, silver and arsenic each increase the annealing temperature of copper, but together they do not produce an effect greater than one alone.

Iron — There is a certain amount of disagreement concerning the limits of solubility of iron in brass. Regardless of this, some is picked up from scrap contaminated by tramp iron, or it could be obtained from aluminum bronzes or so-called manganese bronzes, both of which contain varying amounts up to about 4.0% iron. As an impurity, iron affects annealing primarily, and some students of the problem believe it acts in erratic fashion. Part of the discrepancies might be concerned with the current belief that iron can precipitate from the alloy which, if so, could account for varying degrees of hardness resulting from certain annealing tests. It is not necessary in this discussion to do more than recognize iron as a grain growth restrainer.

One set of results shows the following effects on grain size (comparison with data in previous chapters is not possible because of the differing reductions prior to annealing):

Temperature	Less Than 0.02% Iron	Approx. 0.1% Iron
800° F.	0.030 mm.	less than 0.010 mm.
900° F.	0.040 mm.	less than 0.010 mm.
1000° F.	0.070 mm.	0.020 mm.
1100° F.	0.110 mm.	0.060 mm.

There is also a hardening effect of iron, naturally, since grain growth is suppressed. This hardening effect, as shown on the annealing curves of Fig. 9, page 20, appears generally as an upward bulge in hardness between 1000 and 1200° F. Most specifications limit iron to 0.05% max. to keep the annealing characteristics under control.

Lead, similarly to bismuth, selenium and tellurium, is not soluble in copper or copper alloys. (Metallographically, it appears as small globules or as streaks, the appearance varying according to cross section and lead content.) Its presence in scrap has been mentioned. The reason for its addition is to impart free cutting quality, the chips breaking very readily. In hot or cold working it tends to create a weakened condition. In hot rolling it appears as hot shortness and lead must be kept under 0.02% to roll a brass successfully in the hot mill. (Alloys containing up to 4% lead are hot worked by extrusion processes.) For cold working, the severity of the operation plays a considerable part in the allowable tolerance. Alloys containing as much as 2% lead can be made to take shallow draws — with appropriate anneals and generous radii on tools — or be cold headed to a degree. However, because lead lowers ductility of the alloy, maximum allowance for severe working is 0.07%; the ductility progressively decreases, until at 2% lead only about half the cold reduction of lead-free

material can be done in the brass rolling mill. Lead tends to suppress grain growth somewhat during annealing.

Nickel — Aside from plating, cupro-nickel (70% copper, 30% nickel) is the main source of nickel in scrap. Aluminum bronzes and so-called manganese bronzes may contain nickel in relatively small amounts — less than about 5%. In conjunction with silicon and more particularly beryllium, it forms a precipitation hardening compound. Nickel increases toughness and resistance to annealing. As an impurity, nickel is a grain growth restrainer; for example, 0.16% nickel produces a 0.090 mm. grain size for a 1300° F. anneal, whereas the same alloy with no nickel shows a 0.120 mm. grain size. The effect is less noticeable apparently with lower temperatures, since at 1000° F. both alloys were 0.030 to 0.035 mm. in grain size.

Phosphorus — Practically all copper tubing contains phosphorus, in amounts from 0.015 to 0.040%. The same is true of sheet and plate for welding purposes. These can serve as scrap sources of contaminant. Since phosphorus tends to oxidize readily, there is less tendency to appear in brasses upon remelting than other elements. Regarding the amounts or tolerances it may be said that no adverse effects on working are caused by 0.04% and less phosphorus, but on annealing grain growth is restrained. As an example, annealing a phosphorus-free 70-30 brass at 1050° F. produced grain size of 0.040 mm., but the addition of 0.008% phosphorus decreased the grain size to 0.020 mm. With larger amounts of phosphorus, strength is increased and elongation lowered upon annealing. For example:

Phosphorus Content	Annealing Temperature	Tensile Strength	Elongation in 2 In.
0.04%	750° F.	63,000 psi.	43%
None	750° F.	55,000	50
0.04%	1300° F.	49,000	66
None	1300° F.	45,000	74

Tin — Tin plated copper alloys are quite common and can be sources of tin in scrap, although admiralty metal and naval brass (60% Cu, 0.75% Sn, balance Zn) are more common contaminants. There are also large tonnages of scrap phosphor bronze, containing up to 10% tin, which are commercially available also. The high price and scrap value of these alloys, however, sharply accent the need of scrap sorting. As an impurity, tin does not affect processing adversely, although it is claimed to induce fire cracking, especially with iron above normal limits. As little as 0.5%, however, commences to lower ductility and increase strength to a noticeable degree. Above about 4.0% hot working is not commercial. Cold working of tin-bearing brass is successful, but becomes more limited as tin increases because of the increasing work-hardening rate.

Minor Elements — There are other minor impurities which can occasionally occur — among them are silicon from silicon bronzes such as Herculoy, Everdur or Olympic Bronze, and silver from silver-bearing copper. However, those elements best known and of most effect have been described. Further and more detailed information on the impurity situation can be found in the following:

D. R. Hull, H. F. Silliman and E. W. Palmer, "Effect of Antimony on Some Properties of 70-30 Brass", Am. Inst. Mining Met. Engrs. Tech. Pub. No. 1552, 1943.

W. B. Price and R. W. Bailey, "Bismuth — Its Effect on the Hot Working and Cold Working Properties of Alpha and Alpha-Beta Brasses", Trans. Am. Inst. Mining Met. Engrs., Inst. Metals Div., Vol. 147, 1942.

B. W. Gonser and C. M. Heath, "Effect of Chromium on the Grain Growth of Brass", Trans. Am. Inst. Mining Met. Engrs., Inst. Metals Div., Vol. 128, 1938.

M. Cook and H. J. Hiller, "Effect of Different Elements on Annealing and Grain Growth Characteristics of Alpha Brass", J. Inst. Metals, Vol. 49, 1932, p. 247.

J. Dudley Jevons, "Metallurgy of Deep Drawing and Pressing", John Wiley & Sons, Inc., 1942.

J. L. Gregg, "Arsenical and Argentiferous Copper", Chemical Catalog Co., 1934.

American Society for Metals "Metals Handbook", 1939 Edition.

The moral of the whole story
is: "Segregate your scrap."

Chapter V—"Season Cracking"

IN CONTINUING THE DISCUSSIONS on cartridge brass and its properties, it is logical to include season cracking, so-called, because of the close association of this phenomenon with the manufacturing and testing of cartridge cases. At the outset, however, it should be recognized that "season cracking" is only a *name* peculiar to the brass industry — a part of brass's jargon, so to speak — and that "stress corrosion" is the proper name of what we are talking about. Stress corrosion is encountered in copper alloys other than brasses, as well as certain types of steels, and in aluminum and magnesium. In fact something that was known to give trouble to cold worked brasses many years ago, and for which various remarkable "cures" were touted, has now been found to cause trouble in a wide variety of industrial alloys. The viewpoint in this article will therefore not be confined to cartridge brass alone.

Further, the approach to the problem recognizes that the requirements of war materials, in respect to freedom from susceptibility to season cracking, are different and far more rigid than for peacetime manufacture. Commercially, however, *economic* life is very definitely a factor which alters the viewpoint toward the absolute necessity for eliminating susceptibility to failure, and relaxes the strict interpretation of the usual tests.

The failure we are now talking about is most often seen as a ragged crack, or cracks — which will be parallel to the long axis of drawn cups or tubes, for example. It may appear in perfectly sound material after a few days, or weeks — or years, even. Inexperienced observers may frequently be baffled by the apparent lack of any observable cause, especially since stress may be thought to be absent.

Three factors are necessary to produce such failures: A susceptible chemical composition, sufficient stress, and corrosion.

In reference to chemical composition — certain of the copper or copper-base alloys are, practically speaking, free from susceptibility to stress corrosion; for example, commercial coppers such as electrolytic (tough pitch), deoxidized, silver bearing, arsenical and oxygen-free copper. Among the brasses are those compositions containing up to 15% zinc (see Fig. 5, page 13, for commercial designations); the phosphor bronzes (copper-tin) and cupro-nickel (commonly containing 20% and 30% nickel) are also immune — although cupro-nickel may crack when highly stressed and exposed to tinning baths, such as the hot tinning of U-bends of tubes. For brasses, the borderline between non-susceptibility and susceptibility is at about 20% zinc. 85-15 red brass has been known to crack when in the form of hard drawn, large diameter, heavy walled tubes. As zinc increases in simple brass alloys to its commercial maximum, susceptibility to season cracking also increases.

Other more complex copper alloys also susceptible are: Naval brass, admiralty, aluminum brass, silicon bronze (Grade A), manganese bronze and certain types of aluminum bronze.

Any user of these alloys would naturally like to know with certainty just what conditions will produce failure and how long it will take. Neither question can be answered

with precision. They *can* be answered by general rules and good judgment. Obviously, if a choice of alloy is possible, using a composition which is not susceptible is the simplest way to avoid it, but economic, fabricating or mechanical factors may prevent. Practically speaking, therefore, the answer lies in *(a)* avoiding stress in the first place, *(b)* treating to remove existing stress or *(c)* eliminating or reducing corrosion. Since *both* stress and corrosion are required, elimination of one of them removes the cracking tendency.

Stress may be internal (within the metal, resulting from cold deformation) or external (from an applied load). The cold drawing of strip into cups, severe or multi-directional bending, tube and rod drawing, and stamping of irregular shapes are examples of cold deformations producing internal stress.

Threshold Stress Must Be Exceeded

It should be made clear, however, that internal stress is not necessarily responsible for cracking. Theoretically and practically it would be rather difficult to insure that any piece of metal is entirely stress-free. What is responsible for most season cracking is a residual stress in excess of a certain threshold value.* It may therefore be convenient, in analyzing season cracking tendencies of a given part, to think of the operations required to produce it, and whether a differential in stress will exist between one portion and another — at the same time considering that this differential will tend to exist if one portion is cold worked or deformed more than another. This condition is frequent because *(a)* a given shape can only be made by deforming in certain areas, *(b)* cross sections may be too heavy for the available equipment to work them uniformly in all parts

*In the presence of mercury, cartridge brass has a threshold value of about 15,000 psi., according to Croft and Sachs.

and *(c)* physical properties induced, within certain limits, by cold working may be necessary.

However, as would be suspected from the foregoing, there is a maximum tendency toward cracking due to internal stress. If a curve is superimposed upon Fig. 6, 8 or 10, roughly dome-shaped with a maximum at 20% cold work, it would represent this *tendency* to season crack. In other words, relatively light reductions produce greater tendency to cracking than heavy, due to the almost unescapable non-uniformity of the working, point to point, and a consequent higher stress differential. At the same time it is obvious that cold reductions of 80%, say, produce such thorough cold working that differences, point to point, are relatively small and cracking tendency may be *nil*.

Other than controlling the amount of reductions to decrease cracking tendency, control of grain size is another means. Small grained material has less tendency to crack than large grained, whether cold worked, or annealed and stressed. In other words, small grain size decreases cracking tendency due either to internal or external stress. However, fabricating or other considerations may prevent the effective use of this palliative; for example, large grain sizes are required for cartridge case disks in order that they may be cupped successfully.

External stress also causes cracking and a threshold value for this stress exists below which cracking will not occur. Since external stress may be indeterminate in typical uses, the only practical manner of avoiding cracking is to use alloys with low susceptibility, *or* avoid unduly high stress. For a great number of industrial applications the limiting stress allowable for mechanical or design reasons will be within safe limits, unless the severe types of corroding conditions exist, as will be specified later.

Practical Methods for Stress Relief

Turning from causes to cures, let's look into the methods by which a fabricated part can be made non-susceptible to stress corrosion cracking. If what we have already said is true, it follows that when the stresses are removed or reduced below the threshold value by stress-relief annealing or by "springing", then the danger is removed. The most widely used cure, most readily applied to a variety of parts, is exposure to heat for time and at temperature sufficient to remove the stresses, *but not to soften the metal appreciably.*

(By definition this operation is not a true stress relief annealing if there is a ponderable change in physical properties in the direction of lowered strength and hardness and increased ductility. On the contrary, an examination of many sets of data on the low temperature annealing of many coppers and copper-base alloys within the range of 300 to 700° F. shows that a slight increase in hardness and strength will occur at some optimum combination of time and temperature. Heating a sample of silver-bearing copper to 600° F. for 30 min. has been known to increase Rockwell B hardness by as much as 6 points. Similarly the effect appears most strongly after heating Type A silicon bronze — 3% silicon — at 550° F. for 35 min., as tensile strength may increase as much as 10,000 psi.)

Generally the stress relief annealing temperatures are between 400 and 700° F. — time being as much as a couple of hours or more at 400° F. and as little as 10 min. *at temperature* for 700° F. As explained in Chapter II, time and temperature factors must be worked out for each individual furnace and part, and stress relief is no exception. If the temperature is too high or the time too long, Rockwell hardness will drop; a maximum allowance of 5 points could be used as a rough-and-ready limit. On the other hand, the

mercurous nitrate test will show whether cracking tendency is still present and, if so, then time or temperature should be increased.

Going to the other extreme of heat treatment it is obvious that recrystallized material is not subject to cracking from internal stress. Unfortunately the physical properties may then be insufficient for the designed use.

"Springing" is the term used to describe the relief of stresses (in rods, tubes or other similar uniformly shaped lengths) by passing the shapes through multi-rolled straightening machines. These straighteners are built analogous to the roller straighteners familiar to the users of sheet metal, with a large number of small rolls arranged in two horizontal rows but with centers offset from each other. Rolls are then raised or lowered the correct distance apart so that the rod going between them is seriously deformed — appearing like a wriggling snake — the last pairs of rolls restoring the rod to straightness. The action is one of deforming beyond the elastic limit in one direction and then in another. The net permanent deformation is zero, since the rod is delivered straight. The efficiency of this method is recognized in the A.S.T.M. Specification for Naval Brass, B21-42T, which says, "Bars that have been properly straightened or sprung will have internal stresses so broken up as not to be in danger of splitting or cracking...."

The method, however, is most applicable to standard mill shapes and is described here because of the need of understanding that a stress relief anneal, as such, is not necessary to protect some brass mill products.

Corrosion Is Also Necessary

The last factor affecting season cracking is corrosion. It is the most variable and the least possible to evaluate

under many conditions. There are, however, some very definite conditions of corrosion which are practically certain to cause cracking if any susceptibility at all exists.

Ammonia is regarded as the most common and powerful in its ability to cause failure. Mercury and mercury compounds are likewise rapid and severe in their action.* Sulphur dioxide in the presence of water vapor and dilute sulphuric acid films are also responsible for trouble. In addition, certain molten metals such as tin and lead can be destructive, either alone or in combination as solders. Cracking occurring in outdoor atmospheres is generally attributed to the presence of small amounts of ammonia, or sometimes sulphur dioxide. Ammonia or ammoniacal compounds in certain plastics have also been found to be responsible.

Recently tests made at Frankford Arsenal by Rosenthal and Jamieson have shown that certain amines cause cracking in the presence of moist air. The primary amines are more active in this respect than the secondary or tertiary types. See Table VII.

The speed of a typical chemical reaction is dependent upon the concentration of the reagents and their temperature. Stress corrosion cracking is no exception in that the time elapsing before failure occurs not only depends upon the corrodent but its concentration and temperature. As a consequence, the evaluation of expected service life, if susceptibility to cracking exists, is no more definite than the knowledge of the corroding conditions. The "standard" test for cracking tendency is an example of a severe condition wherein the corrodent is powerful in its action and failure

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*In addition, it should be noted that ammonia and mercury with their compounds are corrosive to copper and copper-base alloys. Equipment for handling ammonia and mercury and their compounds should be free from the metals under discussion.

can occur quickly. Exposure to strong ammonia fumes is another potent test. Cracking during soldering operations is a third. On the other hand, a chromium plated brass part on your automobile might have cracked under the foregoing test conditions, but in service in normal outdoor atmospheres it will never crack.

Table VII — Effect of Amines on Cracking of 70-30 Brass

Amine	Number of Specimens Cracked*		Number Days Before Cracking	
	Group A	Group B	Group A	Group B
Methylamine	3	3	4	4
Methylamine (retest)	3	3	1	1
Dimethylamine	0	1	R	45T
Trimethylamine	3	3	45T	45T
Ethylamine	3	3	3	3
Ethylamine (retest)	3	3	2	2
Diethylamine	0	0	R	R
Triethylamine	0	0	R	R
Aniline (Phenylamine)†	—	1	—	12
Aniline†	3	1	45T	45T
Diphenylamine†	—	1	—	1
Diphenylamine†	0	1	R	17
Diphenylamine (retest)†	0	0	S	S
Triphenylamine†	0	1	R	45T
Pyridine	0	0	S	S
Ethanolamine†	3	3	4	4
Ethanolamine (retest)†	—	2	—	3
Ethanolamine†	3	1	4	4
Diethanolamine†	—	1	—	8
Diethanolamine†	—	1	—	10
Diethanolamine†	0	1	R	11
Triethanolamine†	—	1	—	1
Triethanolamine†	2	1	45T	17

*3 samples in each group, unannealed 70-30 brass cups, highly stressed since they cracked in 1 min. in mercurous nitrate.

†Tested at 200° F.; the other runs were made at 100° F.

R — Discontinued tests after 45 days.

S — Discontinued tests after 35 days.

T — Cracks found after pickling off corrosion product.

Consequently, for conditions not readily determined as severe, the expected *time for failure* of a given article cannot be judged without some "measure of susceptibility" such as the mercurous nitrate test, coupled with a goodly amount of experience and judgment in its interpretation.

In this connection, the standard of the brass industry is the American Society for Testing Materials' Specification B154, which requires immersion for 15 min. in a solution of 100 g. mercurous nitrate acidified with 13 ml. nitric acid (1.42 specific gravity) made up to 1 liter. Various governmental specifications also add directions for examining the test specimen after the deposited mercury is volatilized, a procedure necessary to detect very small cracks, otherwise covered up.

Certain manufacturing and testing conditions have a measurable influence on this test, and there has been a great deal of excellent work on the effects of various cleaning methods, time of immersion, temperature and concentration of solution. All this has contributed much to the knowledge of the subject. There is not time nor space for detailed discussion, so reference is made to the suggested reading list at the end of this chapter.

It is pertinent, however, to discuss the interpretation of the test in the light of expected usage and service of the parts being tested. In this connection, there is a sharp line of cleavage between war goods and other manufactured parts. All will agree that war goods, such as cartridge cases, primers, fuse and booster parts, are examples of items wherein it is highly necessary to avoid cracking and, as such, are properly subject to rigid testing methods and minute inspection. This is not necessarily true of material outside this category.

From this viewpoint the mercurous nitrate test is *a means of indicating susceptibility,* not necessarily an arbi-

trary test which does or does not produce a crack however minute. As an example: A part which cracks within 5 min. with audible sound when immersed can generally be judged to be in such a condition that stress relief is advisable, even for the general run of commercial articles. However, microscopically fine cracks, appearing only when mercury is removed, would be an indication that failure would only occur under severe corroding conditions.

There is not sufficient experimental evidence as yet to permit one to predict the expected service life, knowing the length of time before cracking occurs in the test. Under the conditions of exposure in most outdoor atmospheres, experience shows that long service life without failure may be expected in parts which, when tested in mercurous nitrate in the standardized way, emerge with only minute cracks.

Identification of Failures

If cracking has occurred in service, then the question arises as to the proper means of identification. How can we be sure it is an example of stress corrosion? As previously stated, characteristic "season cracks" occur longitudinally in tubular articles. In cups they start at the rim and peter out part way down. They are usually ragged in appearance. Under the microscope the identification is more positive; under most conditions the crack will follow the grain boundaries and there will be no evidence of crystal deformation (the latter being more typical of failure due to overstress). By way of further identification, a crack caused by fatigue travels *across* the crystals. In other words, season cracking is inter-crystalline, and fatigue is trans-crystalline (see Fig. 42 and 43).

There can be, however, a condition which causes cracks which run both between and across the grains at the same time, and thus far this seems to be typical of the action of

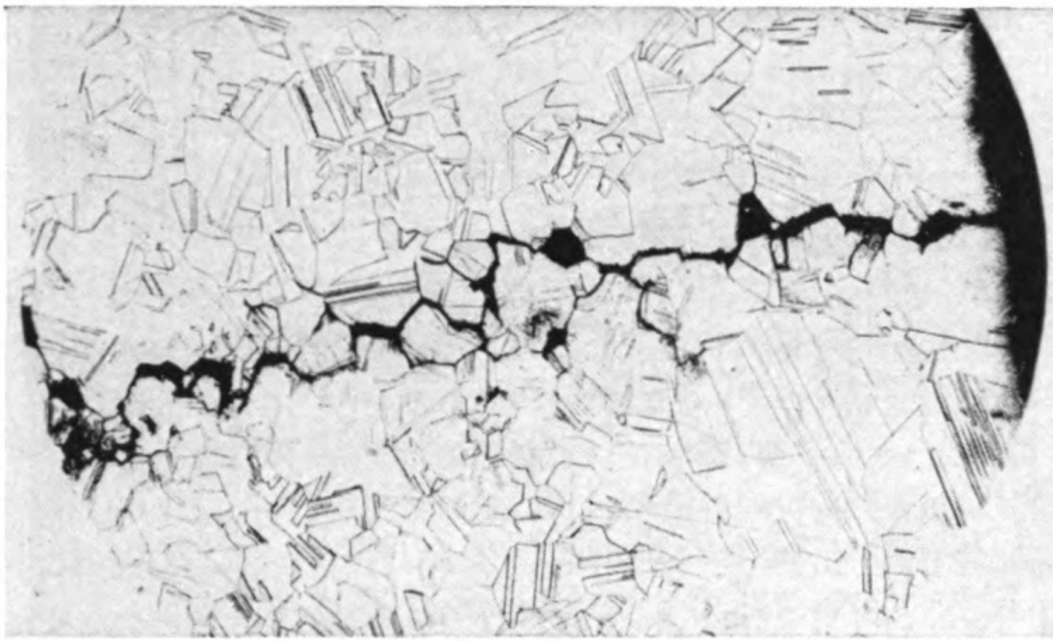


Fig. 42 — Typical Season Crack in Cartridge Brass, at 75 Diameters. Note the inter-crystalline nature and lack of deformation of grains alongside fissure

ammonia on an externally stressed part. Figure 44 shows the result of an experiment at the Schenectady Works Laboratory of the General Electric Co. Note the presence of some trans-granular cracks. However, the presence of numerous inter-crystalline cracks alongside and across the main fissure, especially near the surface, prevents this from being mistaken for a fatigue failure. In these tests at General Electric Co., specimens were exposed to ammonia vapor while bent into a U-shape. The alloy was aluminum brass used for condenser tubing (76% Cu, 2% Al, balance zinc, with arsenic added to inhibit dezincification).

In Summary

1. Season cracking can occur when:
   (a) Metal composition is inherently susceptible;
   (b) Internal or external stress exists, above a certain threshold value;

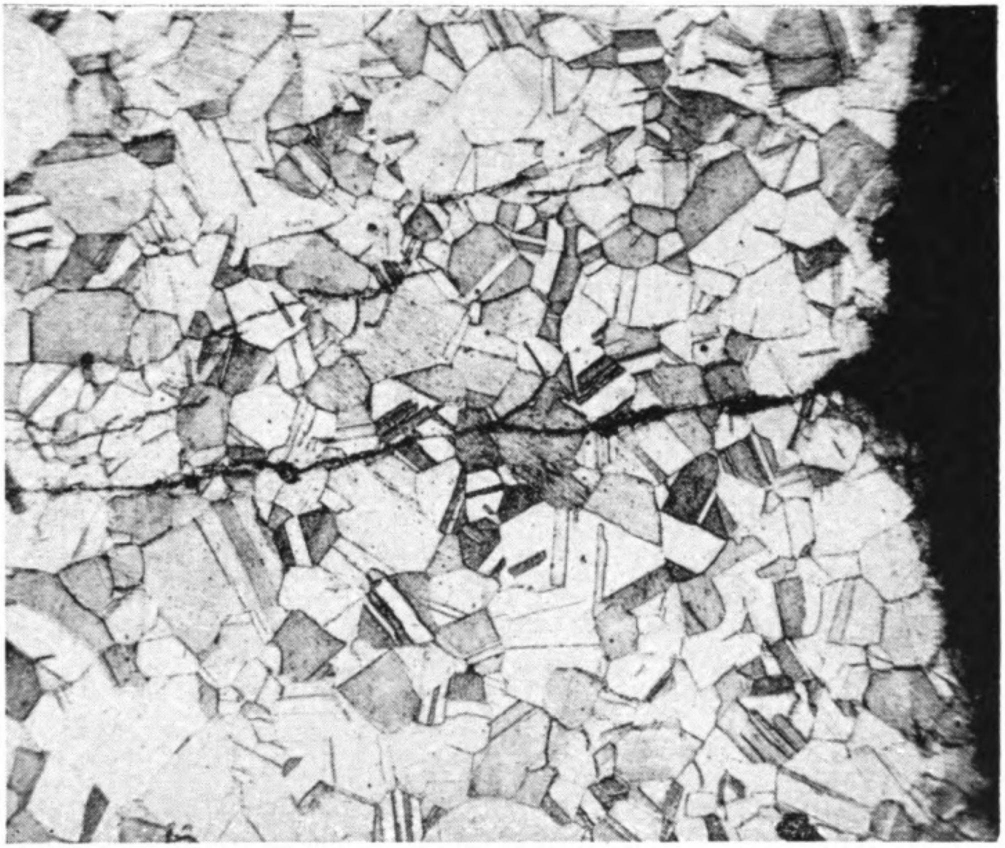


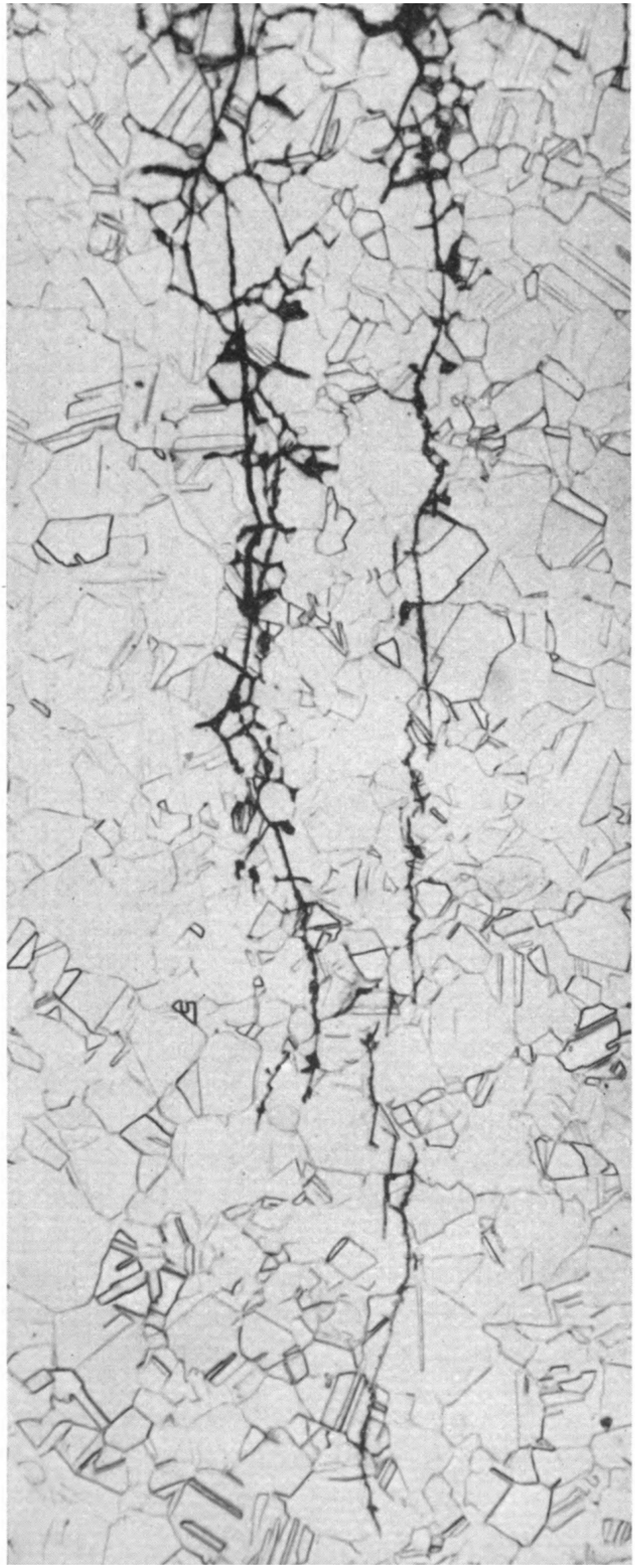
Fig. 43 — Fatigue Crack in Fine Grained Brass, Starting at a Corrosion Pit. Note that the course of the fissure is trans-crystalline. Magnified 250 diameters

(*c*) Corrosion is present, generally due to certain agents.

2. Failures may be avoided by:
   (*a*) Use of non-susceptible alloys;
   (*b*) Thorough cold working;
   (*c*) Stress relief annealing or recrystallization.

3. The method of testing brass for cracking susceptibility requires immersion in mercurous nitrate solution, and should be interpreted with due regard to use of the parts being tested.

4. Service failures may ordinarily be identified microscopically by inter-crystalline cracking, although ammonia may cause a dual inter-crystalline, trans-crystalline fissuring.



Suggested Reading

1 (A). W. Lynes, "Comparative Value of Arsenic, Antimony and Phosphorus in Preventing Dezincification", Proc. Am. Soc. Testing Materials, Vol. 41, 1941.

(B). H. Rosenthal and A. L. Jamieson, "Mercury Cracking Test — Procedure and Control", Proc. Am. Soc. Testing Materials, Vol. 41, 1941.

(C). H. P. Croft, "Influence of External Stresses on Tendency of Brass Wires to Stress-Corrosion Crack, as Indicated by the Mercurous Nitrate Test", Proc. Am. Soc. Testing Materials, Vol. 41, 1941.

2. H. P. Croft and G. Sachs, "Stress Cracking of Brass", Iron Age, March 11 and 18, 1943.

3. D. K. Crampton, "Internal Stress and Season Cracking in Brass Tubes", Am. Inst. Mining Met. Engrs. Tech. Pub. 297, 1930.

4. Alan Morris, "Stress-Corrosion Cracking of Annealed Brasses", Am. Inst. Mining Met. Engrs. Tech. Pub. 263, 1930.

5. H. Rosenthal and A. L. Jamieson, "Stress-Corrosion Cracking of 70-30 Brass by Amines", Am. Inst. Mining Met. Engrs. Tech. Pub. 1660, 1944.

Fig. 44 — Combination Inter-Crystalline and Trans-Crystalline Crack in Aluminum Brass Condenser Tubing, at 500 Diameters, Caused by Ammonia and External Stress. Courtesy Schenectady Works Laboratory, General Electric Co.

Chapter VI
Special Properties and Physical Testing

IN THE PREVIOUS CHAPTERS the various terms for physical properties have been used without precise definition of their meaning, or of the methods for obtaining the numerical values, although considerable elementary matter was introduced at the very outset to make the terms intelligible to the reader who is not a metallurgist. It is well, now, to spend some time on the methods for making common physical tests, for in discussing the general subject in day-to-day work with users of copper alloys there have been a number of questions arising concerning test methods. Some of these will be discussed in the following. It appears convenient to subdivide this chapter according to the *form* of specimen used and the *values* determined from them, such as tensile, hardness, metallographic and special.

Tensile Testing

In testing for tensile strength, the most convenient specimen for material delivered from the mill in the form of rods seems to be a round specimen with a reduced center section and non-threaded ends. The reduced section is commonly 0.505 in. diameter with a taper of 0.002 in. approximately to the center. Most specifications recognize

that rods over 1½ in. in diameter are cold worked but little at the center, and an axial specimen would therefore not represent the approximate average of the entire bar, so the specimen axis on large rounds is at one-quarter the diameter of the original sample.

For plate or strip specimens a reduced section is characteristic (except that strip less than 1 in. wide and light gage, say 0.010 to 0.015 in. and under, may be pulled full size). Any important tonnage of strip is made for ammunition components as well as for cable wrapping, shim stock, radiator metal, diaphragms, flexible hose and the like, so it may be well to mention several points in the technique of "pulling" such specimens. The thinner the gage, the more difficult it is to hold the sample in the grips without inducing failure at the grips, and to localize the "break" in the center somewhere between gage points. Commercial types of grips used for textile or similar testing, wherein the material is wrapped around a block before gripping, will be of great aid when testing thin gages. Other types of grips can be used but require very fine serrations on the jaw face, they must be kept spotlessly clean, and the sample lined up perfectly to prevent stress concentrations and breakage at the wrong point.

If a large number of samples of similar size and gage are to be tested, it will pay the laboratory to prepare a die to blank a reduced section. The die should be made with close enough clearance so the edges will not tear, else premature fractures at the tears will likely occur during the testing. Another method, also applicable to heavier specimens, is to use a contour milling cutter; the best type mills both the ends and the reduced section, and the cutter is run across a number of specimens, clamped together, to produce the profile. In either method it is preferred practice to stone the edges of the reduced section for a smooth surface.

Fig. 45 — Tension Test on Strip, Being Made in a Small Amsler Machine at Bell Telephone Laboratories

Interpretation of results of tensile tests is a straightforward job in most cases. However, numerical values for heavy sections will be lower than for light sections (in cold worked material particularly) because, as mentioned before, the effect of cold working will not penetrate uniformly through the entire cross section.

All in all, the tensile strength is probably the most reliable value for specification use or for determining the physical condition of all copper-zinc alloys, especially in cold worked condition. This does not mean that tensile tests should be required for *all* acceptance work, since other properties may serve equally well or better, and be less of a burden in the testing laboratories of both consumer and supplier. Examples are Rockwell hardness for tubing and commercial tempers of strip, and grain size for annealed tempers of tubing and strip to be used for subsequent cold forming.

In connection with specifications, it might be mentioned here that it is impractical in the brass industry to segregate and record properties of the mill production, heat by heat, as is often required of steel manufacturers. The simple truth is that brass ingots (casts) may be as light as 200 lb. or as heavy as 3000. (The 2000 and 3000-lb. cakes for cartridge brass have been typical of wartime plants, and not of peacetime.) To keep track of each cast during subsequent processing not only would be a tremendous burden, but is also considered quite unnecessary since it would serve no useful purpose. Chapter IV has mentioned the systems enforced to keep alloys segregated by composition and to insure a product up to standard.

Elastic Properties

Routine checking of the "0.5% yield strength", most commonly called for, is done during the tensile test, either

with autographic, optical or mechanical strain gages of various types. A discussion of them or their merits does not belong here, but the instrument manufacturers can help the hard-pressed control laboratories a great deal by defining more precisely their capabilities and field of use.

The various methods and numerical values used to describe the "elastic properties" can provide subject matter for a very considerable tome. However, a brief description of these methods and some of the advantages and disadvantages seems quite pertinent.

Yield Strength is defined by the American Society for Testing Materials in Specification E6-36 as "the stress at which a material exhibits a specified, limiting, permanent set". The Federal Specifications Board is of the same mind but uses different language in Specification QQ-M-151a: "The load per square inch of original cross sectional area which causes a specified set, as measured by the offset method or a specified extension under load" (paragraph 37d). It also mentions two methods used to determine the value for yield strength: The "offset" method shown in Fig. 49, page 94, requires a recorded stress-strain curve; the numerical value represents the intersection of a line which is parallel to the curve's tangent at a distance of 0.1% (or 0.2% if 0.2% offset is specified) of the original gage length. It is assumed that such a value represents the approximate permanent set of 0.1% (or 0.2%) which would occur if the load were released and the gage length remeasured. (The reader should refer to the two specifications for detailed descriptions.) The second, or "extention under load" method described in the Federal specification, is merely the stress required to produce 0.5% extension under a given load; most commonly this value is called the "0.5% yield strength".

Elastic Limit is "the greatest stress which a material is

capable of developing without a permanent deformation remaining upon complete release of the stress", according to A.S.T.M. E6-36. The Federal specification is more specific, stating in paragraph 37a that elastic limit is "the greatest load per square inch of original cross sectional area which, when removed, has not caused a permanent elongation exceeding 0.00003 in. per in. of gage length". Other methods, such as "Johnson's elastic limit" and the "apparent elastic limit" mentioned in previous chapters, attempt to determine the value through an approximation which is good enough for general use.

Proportional Limit, according to paragraph 37b of Federal specification QQ-M-151a, is "the greatest load.....for which the elongation is proportional to the load".

While these definitions are simple enough, the meanings or utility of the various values obtained are not readily apparent, nor are there any simple methods for determining these values when utmost accuracy is required. For specification work and the acceptance of material, the 0.5% yield strength is widely used. It is easy to determine. It is, therefore, an eminently practical test from the brass mill's standpoint, especially if a tremendous number of tests are required, as is true in wartime. On the other hand it has its limitations and is of very doubtful value in showing a designer the useful elastic properties of cartridge brass, copper or many another of the extremely ductile copper base alloys to which it is applied. The 0.5% yield strength retains no constant relationship to the tensile strength as the *temper* varies; neither does it necessarily show a fixed relationship to tensile strength as the *alloy* varies. As examples, in hard drawn copper the 0.5% yield strength is nearly the same figure as tensile strength, but in an aluminum-silicon-bronze the value is considerably lower in proportion (see Table VIII). For comparisons in cartridge

Table VIII — Variability of "Yield Strengths" With Temper and Alloy

Property	Electrolytic Copper		7% Al, 2% Si Bronze, Cold Drawn 10%
	Annealed	8 B&S Numbers Hard	
Tensile strength	33,500 psi.	56,900 psi.	95,000 psi.
Elongation in 2 in.	55%	4%	25%
0.5% yield strength (extension)	9,600 psi.	54,000 psi.	54,000 psi. *(a)*
0.2% yield strength (offset)	8,600 psi.	53,000 psi.	63,000 psi.
0.1% yield strength (offset)	7,700 psi.	48,000 psi.	50,000 psi.

(a) The anomaly that 0.5% value is less than the 0.2% value is explained by a more inclined slope of the early tangent portion of the stress-strain curve for this cold worked material. See Fig. 28.

brass see Fig. 8 and 9 in Chapter I and Fig. 46, 47 and 48 herewith.

The "offset" yield strengths are somewhat more consistent in their relationships to the tensile strength, as Fig. 46 and 47 show (and sometimes are more conservative, as they are for copper). However, the offset method has at

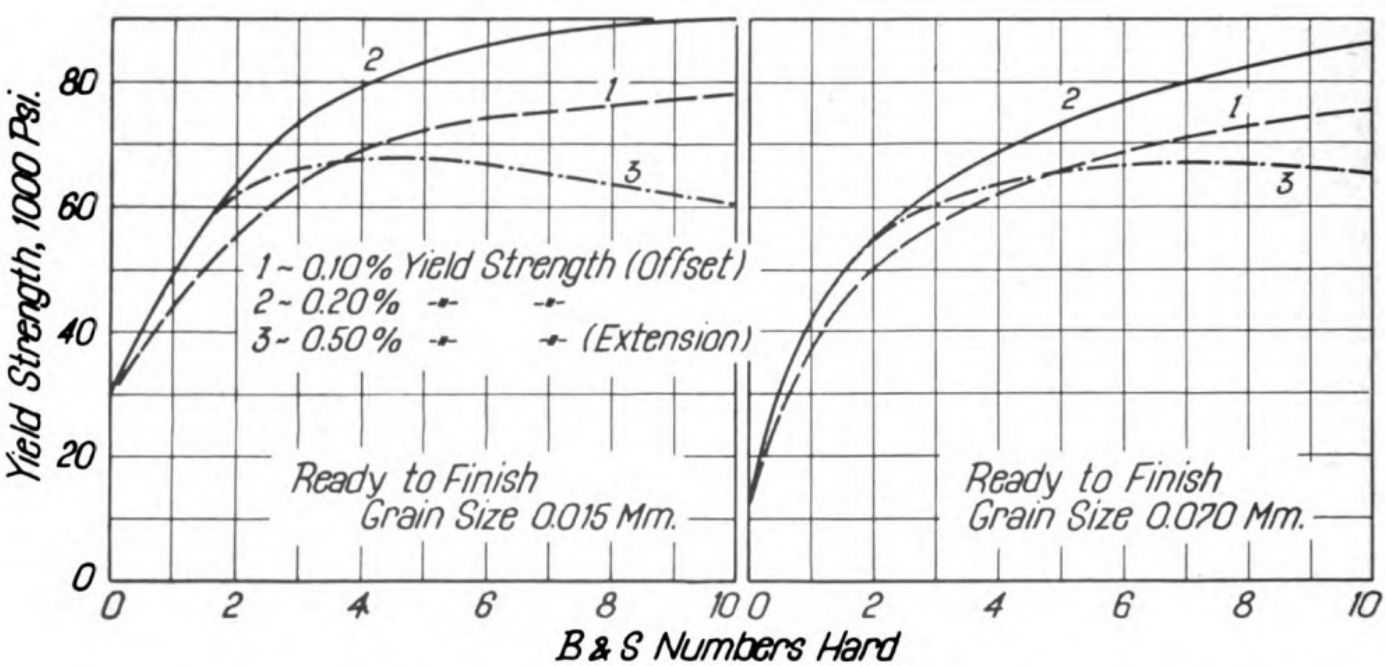


Fig. 46 and 47 — Yield Strength of 70-30 Cartridge Brass Strip as it Varies With Method of Determination, Temper (Cold Work) and Ready to Finish Grain Size (Fine at Left, Coarse at Right)

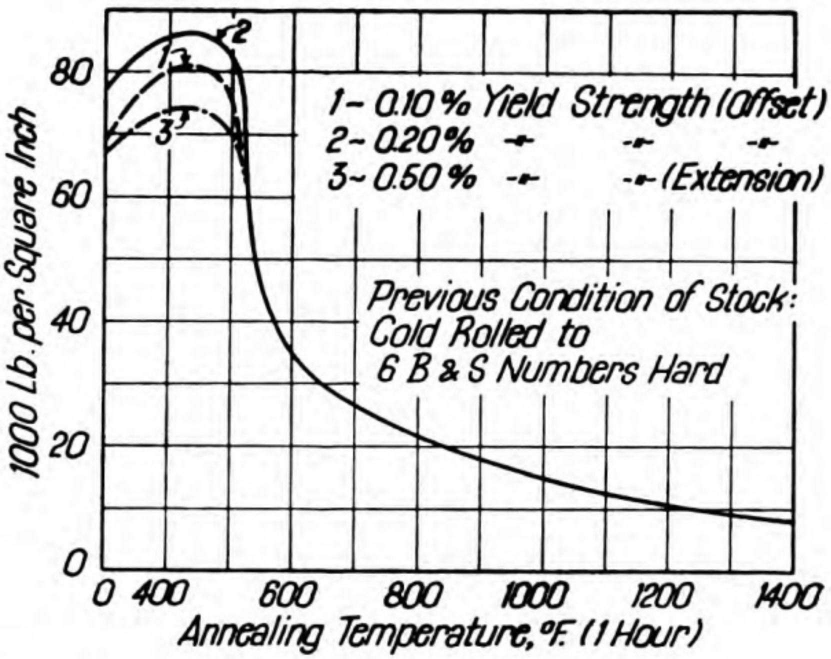


Fig. 48 — Annealing, Even at Low Temperatures, Erases Most of the Difference Between the Various "Yield Strengths"

least one objection and that is that it depends upon a tangent being drawn, and it is not always an easy thing to draw it accurately. (While speaking of tangents, the "proportional limit" suffers the same handicap and furthermore seems to show lower values, generally, as the sensitivity of the extensometer increases.)

The troubles of determining elastic properties stem from the smooth stress-strain curves typical of many nonferrous alloys, including those of copper as well as of aluminum and magnesium. (In copper alloys there has not, until relatively recent years, been a demand for accurate stress values because of the large tonnage in nonstressed parts. In strong aluminum alloys the condition is just the reverse.) The curves in Fig. 49 show the actual stress-strain curves for soft and hard cartridge brass strip, respectively; the strain increments are the same, but the stress values are not, which provides a longer curve for the annealed material. The various points under discussion are illustrated in these curves. It is apparent in the hard

sample at the right that a question of judgment exists as to the exact tangent position, but since our experience indicates the curve should have been straight at the lowest portion, rather than convex to the right as shown, the tangent was so drawn and the strain values measured from it. The "proportional limits" (12,500 ± and 32,000 ± psi. for the annealed and hard samples respectively) are obviously

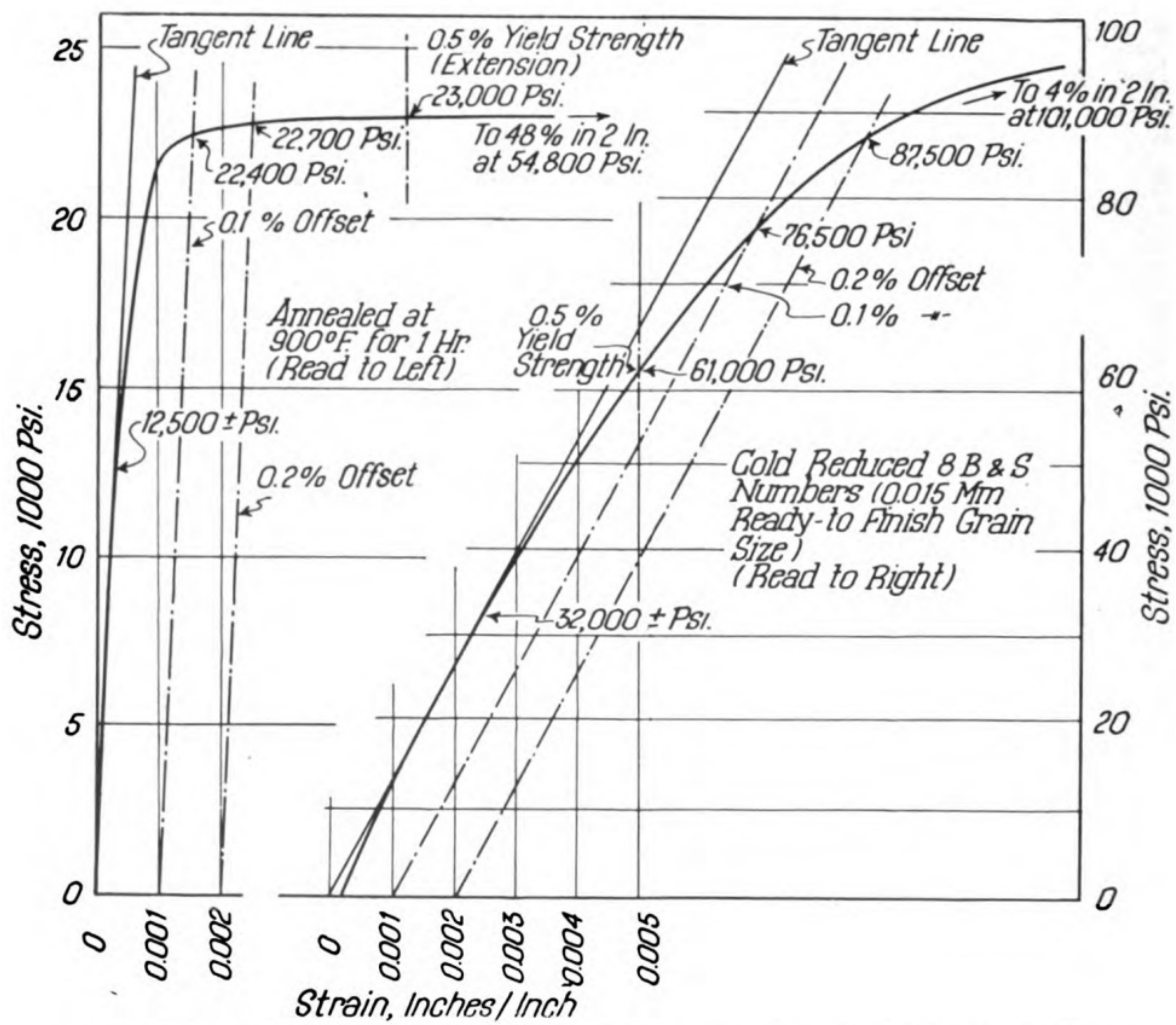


Fig. 49 — Typical Stress-Strain Curves for Annealed Cartridge Brass (at Left) and for Material Cold Rolled 8 B&S Numbers Hard. Yield strengths by offset and extension are about the same for annealed brass. For hard drawn material 0.5% extension may occur at a lower stress than the 0.1% yield determined by offset

much lower than any of the other tensile properties, as defined in the usual specifications.

There exists a well-founded belief that a stress required to produce a very small but definite permanent set is probably a good representation of the stress the designer should have in mind, such as the "elastic limit" of the Federal specification. However, the basic fact seems to remain that the *creep strength* is the ultimate in the determination of load-carrying ability. It is to be hoped that some day the necessary considerable time and skill will be spent on correlating the relationship between the elastic limit and creep strength so that the design figures can be known. It is also desirable to discover a relatively quick test to reveal the true elastic properties of such alloys as cartridge brass.

More in the way of commentary are the figures in Table IX, which include creep rates at 300° F., but since no softening took place after 5040 hr., they are judged to be comparable with room temperature values. Figure 50, while not showing true creep strengths, gives some available information from tensile tests made under closely controlled conditions and at moderately elevated temperatures. The elongation curve showing a decrease in elongation at two

Table IX — Creep Strength at 300° F. Versus Yield Strengths of Cartridge Brass Rod Cold Drawn 37% From Fine Grained Material

Property	A Single Test *(a)*	Expected Range
Tensile strength	86,000 psi.	85,000 to 90,000 psi.
0.5% yield strength (extension)	62,000	60,000 to 65,000
0.2% yield strength (offset)	—	65,000 to 70,000
0.1% yield strength (offset)	—	58,000 to 65,000
Creep strength *(b)*	24,000	—

(a) From "Creep Characteristics of Some Copper Alloys at Elevated Temperatures" by H. L. Burghoff, A. I. Blank and S. E. Maddigan, *Proceedings* A.S.T.M., 1942, Vol. 42.

(b) 0.01% per 1000 hr. at 300° F.

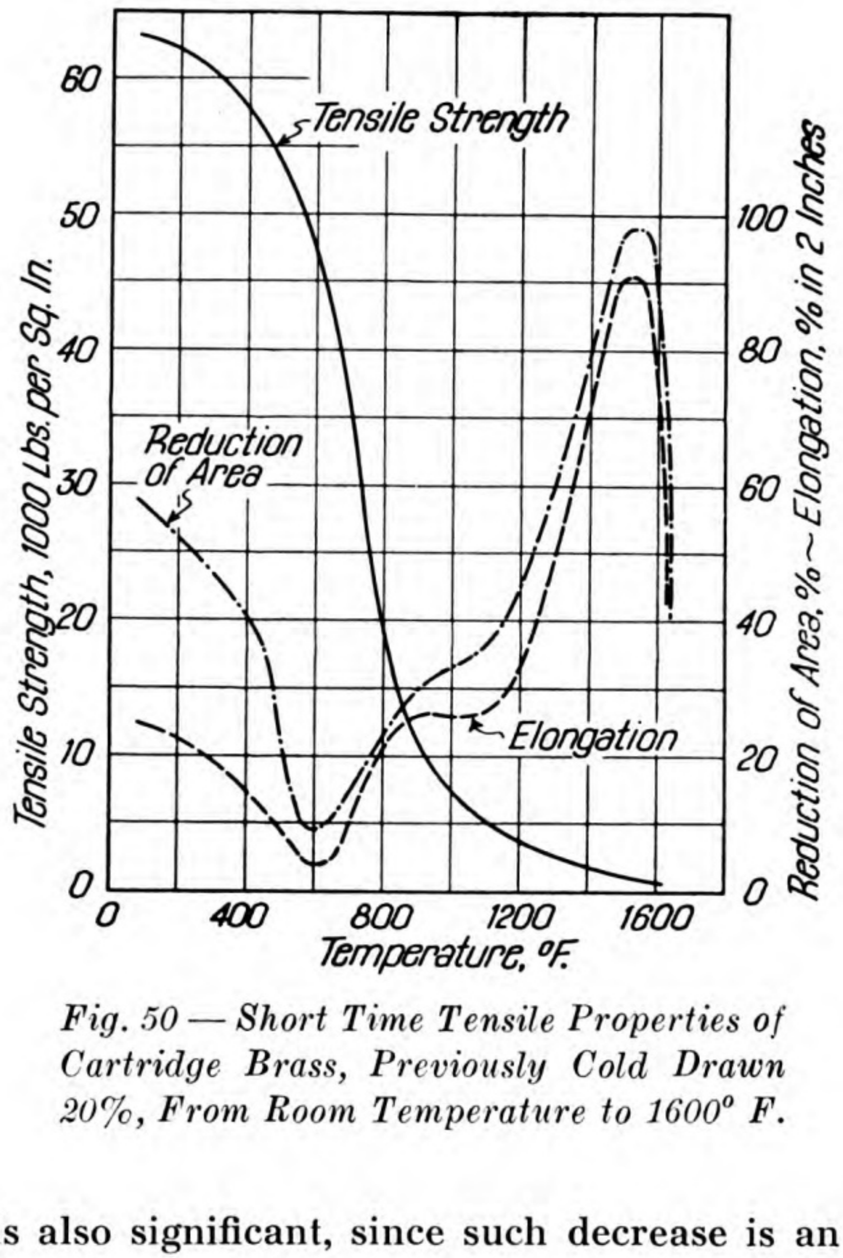


Fig. 50 — Short Time Tensile Properties of Cartridge Brass, Previously Cold Drawn 20%, From Room Temperature to 1600° F.

points is also significant, since such decrease is an indication of hot shortness at these temperatures.

Elongation and Reduction of Area

The commonest gage length is 2 in., but 8 and 10 in. are also used for small rods and light metals, respectively. In this connection, many of the Government specifications, for rods particularly, call for "elongation in 2 in., or four times the diameter". This qualification becomes important for small sizes of very hard drawn rods. Numerical values in

the order of 10% elongation for ½-in. rod may not be reached on ⅛-in. diameter rod of similar tensile strength. The effect of specimen size on elongation is well established by metallurgical work, and this accounts for the unnaturally low figures for elongation, but some specifications still do not recognize it as completely as they should.

It will be found that some copper alloys "neck down" much more than others, which not only affects the reduction of area (the more contraction the higher the numerical value), but also the elongation. Much of the stretch in copper and copper-zinc alloys (also in silicon bronze and cupro-nickel) takes place in the necked down area. Consequently, the testing engineer should observe the rule which allows a retest when the break is outside of the middle third of the gage length; otherwise elongation values are apt to be low. The beta-containing materials, such as free-cutting brass rod and Muntz metal, do not show this to such a degree as the alpha alloys, which are our principal concern in this book.

Very probably the values for elongation and reduction of area will together provide a good clue to the ductility of copper base alloys. For example, Fig. 10 and 11 in Chapter I illustrate two pertinent points: *(a)* Elongation is high in the annealed condition, about 75%, and so is reduction of area, and *(b)* the reduction of area decreases at a slow rate with cold work. Other alloys such as Grade B silicon bronzes and 70-30 cupro-nickel show similar effects — that is, reduction of area of 85 to 90% as annealed, with high elongation, and even less decrease in reduction of area by cold work than is observed in cartridge brass. These alloys are superb for cold heading operations, for manufacture of bolts and the like.

Hardness Testing

Brass mills have settled upon the Rockwell hardness test as standard for the majority of their products and have any number of good reasons for it. The test methods are well understood and are quite specific; also the limitations on the various scales of hardness are known. Correlation of the various scales is shown in the diagram tipped in to face page 98. We do not like to use the F scale above F-90 hard, preferring the B scale, nor do we feel that above B-95 we are obtaining true readings. On the soft side, F-20 to F-25 is representative of dead soft copper and we rarely go lower. Neither do we use under B-20. For light metals the superficial scale is popular and, while it may not show precise hardness on copper 0.005 in. thick, when used with diamond anvils it is successful in controlling the temper of production lots so that subsequent fabricating can be done without failures.

It should be mentioned that tubes should be cut open and the test made on the inside for consistent results — except on small bores when the penetrator will not fit; in this case a close-fitting steel plug is frequently used as a support against collapse when tests are made on the outer surface. Furthermore, the penetrator will bulge rounds of small sizes if F or B scales are insisted upon, which means the surface should be filed flat for accurate testing. Another special condition is a wedge shape or angle bar which must be fitted to a supporting block which corrects the surface so that it is absolutely normal to the penetrator: very serious errors can result from testing angle sections without such support and correction.

Of the various other methods, the Vickers hardness testing machine is expensive but it has the advantage of a constant scale which is directly comparable for hard and

Kodachrome photogr
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Fig. 51—

Fig. 52 — Dezincification. A Typical Red Copper Plug Re-Deposited in the Corrosion Pit in the Yellow Brass. (Etched Microsection). Color photography by R. D. Destito; Samples prepared by W. Jenks; All magnified 75 diameters

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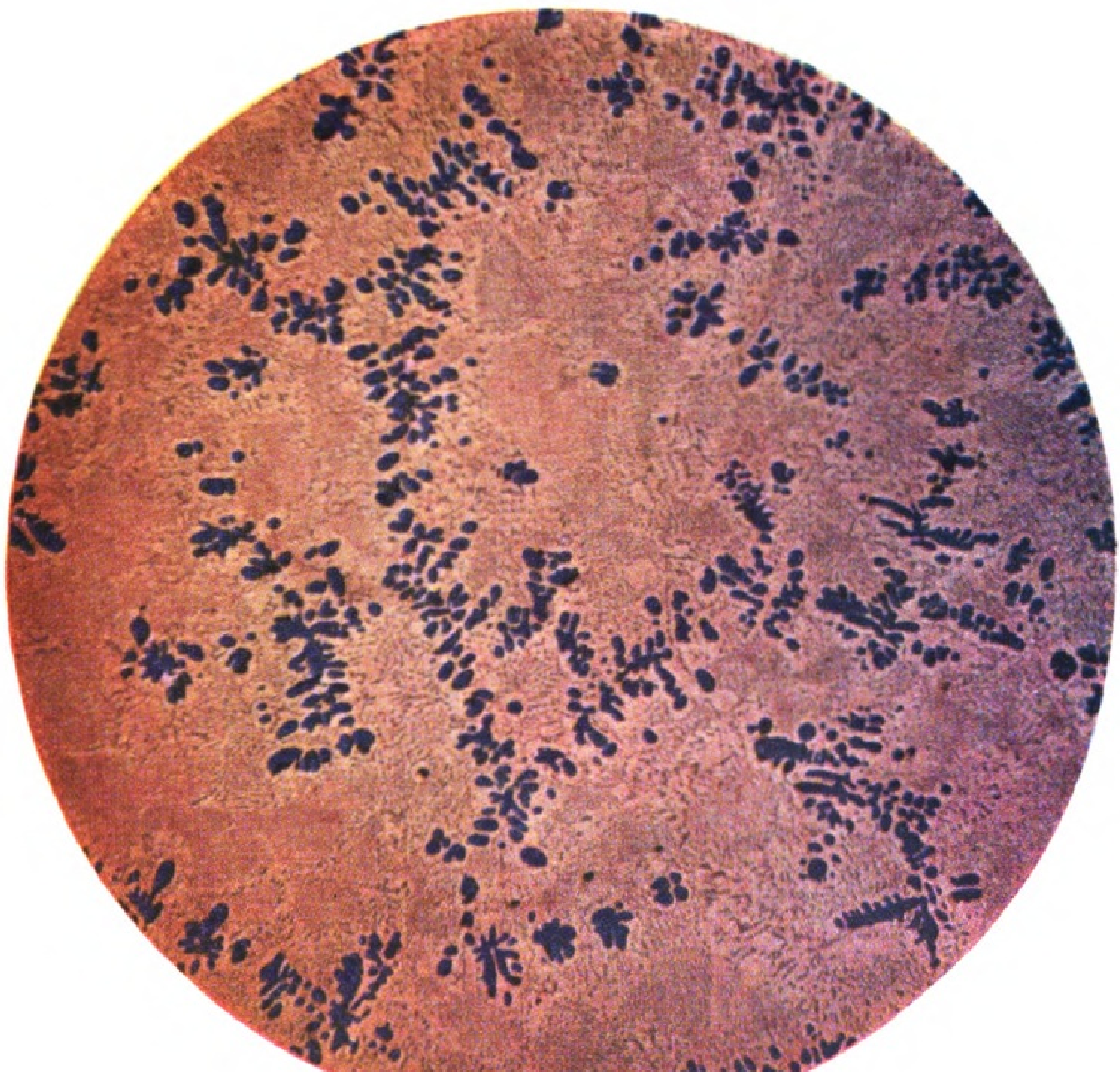

Fig. 53 — Unetched Sample of Copper, Designedly Made With Very Large Amount of Oxide. Dendritic Structure Is Typical, as Well as the "Finger Print" Appearance of the Eutectic (Copper and Copper Oxide) in the Background

soft ranges. Brinell hardness tests are used for heavy plates, say above ¼ in. thick, or for large sections where adequate support can be had around the ball penetrator and its accuracy is unquestioned. For sections which are so light that anvil marks are noticeable or for others not large enough in area for ball support, we feel the Brinell method is unreliable. Specifications not recognizing these limitations are believed to be inadequately drawn up, because large amounts of material are made which do not fall within the scope of the test.

Metallography

Various structures of common copper materials including cartridge brass are shown facing pages 10, 58, and 99. These give a good comparison of the constituents.

The beta brass in Muntz metal types should not appear in cartridge brass, as is obvious from the constitutional diagram. The specimen of oxidized copper is very rich in oxides, being made specially to show the typical color and structure in an exaggerated way. Obviously oxide should not be found in cartridge brass, even though it will appear in small amounts in tough pitch electrolytic copper and in the other commercial coppers which have not been completely deoxidized — where it is not regarded as a detriment.

Skill plays a great part in the preparation of metallographic samples. Standard etching reagents are well covered in Metals Handbook, page 1471 of the 1939 edition.

Standard grain sizes have been referred to in Chapter I, and are as shown in the A.S.T.M. Specification E2-39T (reproduced facing page 11).

Table X — Miscellaneous Data on Cartridge Brass

Melting point	1750° F. or 955° C.
Coefficient of expansion —	
per °C. from 25° to 300° C.	0.0000199
per °F. from 77° to 572° F.	0.0000111
Electrical conductivity	27% of International annealed copper standard
Thermal conductivity per sq.ft. per ft. per hr., per °F. . . .	70 Btu.
Density (lb. per cu.in.)	0.308
Modulus of elasticity,	Approx. 15,000,000 psi.
Endurance limit — soft	17,000 psi.
Rod, cold drawn 50%	22,000 psi.
Strip, cold rolled 4 B&S Gage Numbers	19,000 psi.
Strip, cold rolled 8 B&S Gage Numbers	22,000 psi.

Special Properties

Miscellaneous Physical Constants are shown in Table X.

Impact strength is high for cartridge brass at room temperatures and, in common with other copper base alloys, the values do not decrease with decreasing temperature. Charpy tests on annealed material are about 85 to 89 ft-lb. from room temperature to —112° F.,* whereas Izod values are about 66 to 79 ft-lb. from room temperature to —292° F. (tensile strength varying simultaneously from 51,000 to 73,000 psi.).† It appears, therefore, that as the temperature decreases the tensile strength increases, but impact properties do not suffer appreciably at sub-zero temperatures.

High temperature strength is poor for cartridge brass, since the general rule is that a time and temperature which causes recrystallization will also reduce the creep strength to so low a figure as to be of little use, practically speaking.

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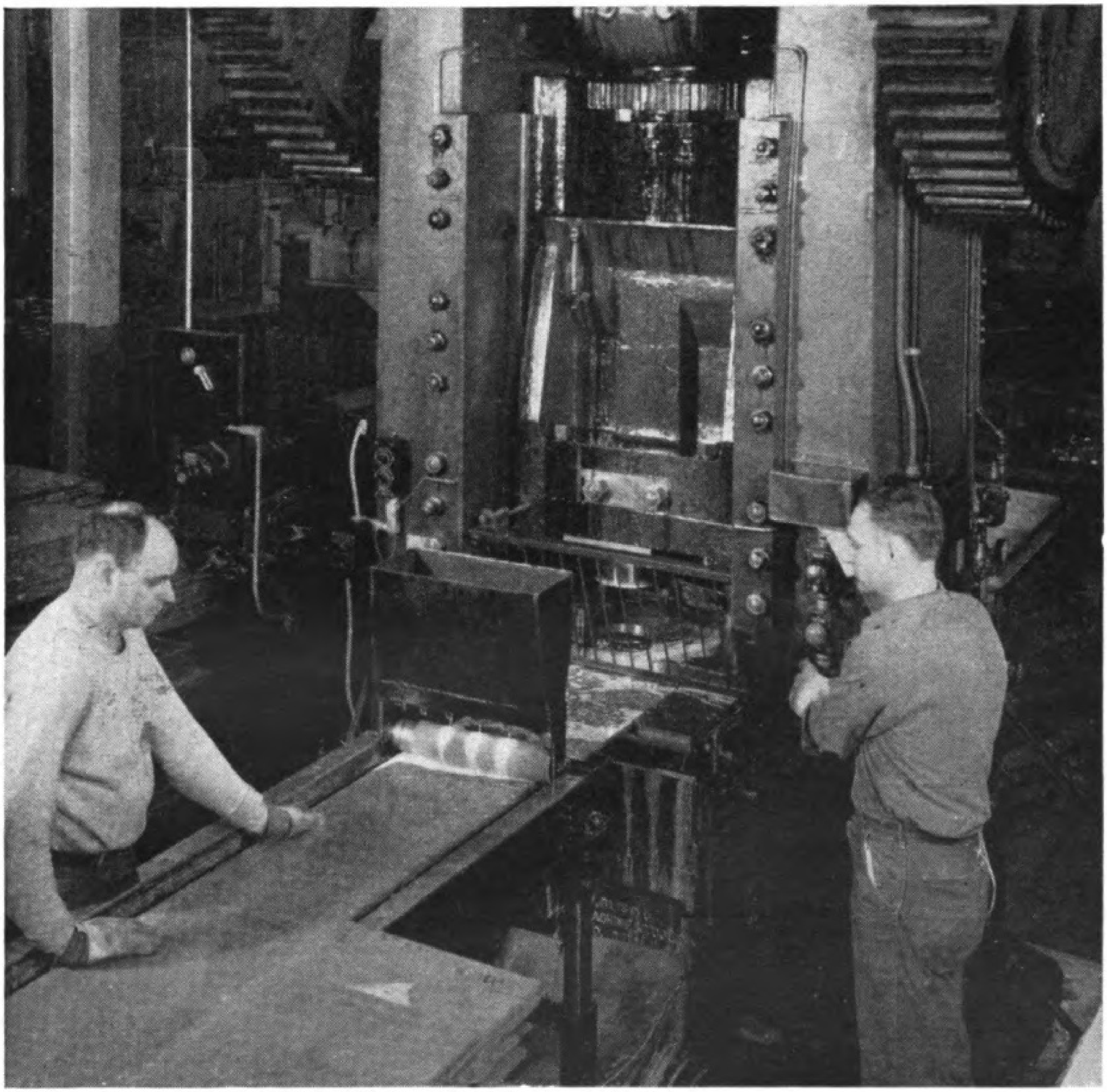
*See "Effect of Low Temperatures on Metals and Alloys" by H. W. Russell, Joint A.S.T.M. and A.S.M.E. Symposium on Effect of Temperature on the Properties of Metals, 1931, page 486.

†See "Some Properties of Copper at Low Temperatures" by C. S. Smith, *Proceedings* A.S.T.M., 1939, Vol. 39, p. 642.

Working stresses for this class of alloy are set up in the A.S.M.E. Unfired Pressure Vessel Code, Table U-3, and limit temperatures to 500° F. with allowable stress, decreasing as temperatures rise from 150 to 500° F. The short-time physical properties at various temperatures are shown in Fig. 50.



Blanking Disks for 155-Mm. Cartridges

GENERAL INDEX